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Measuring Configural Spatial Knowledge with Alternative Pointing Judgments

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MEASURING CONFIGURAL SPATIAL KNOWLEDGE WITH ALTERNATIVE POINTING JUDGMENTS

A thesis submitted as fulfillment
of the requirements for the degree of
Master of Science

By

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B.A., Wright State University, 2003

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Lisa J. Douglas ENTITLED Measuring Configural Spatial Knowledge with Alternative Pointing Judgments BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT

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Measuring Configural Spatial Knowledge with Alternative Pointing Judgments.

Configural spatial knowledge has been tested by having people point from one object to another or by having them sketch maps from memory. Several different pointing judgments have been used, but these judgments appear to differ both in superficial characteristics and in their implied theoretical mental model of spatial representation. This experiment compares two different pointing judgments: judgments of relative direction, based on a quasi-Euclidean model of spatial representation; and object-based judgments, based on an object reference model of spatial representation. Results supported the object reference model. Object-based judgments were more accurate, were made with more confidence and had shorter latencies than judgments of relative direction. Analyses of the sketch maps were consistent with the pointing judgments, suggesting the results reflect stored memory representations and not retrieval differences. Issues of generality of the results and practical ramifications of the research are discussed.

TABLE OF CONTENTS

LIST OF FIGURES

Figure Page

LIST OF TABLES

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I. INTRODUCTION

People routinely obtain spatial knowledge about an environment whenever they move about in it. For example, suppose your hardware store does not have the tool you need, and an employee tells you how to get to another store, a store you have never visited previously. You drive to the new store. Now, you have to find your way back home, often with no additional navigational aids. How can the spatial knowledge obtained from such interactions with an environment be characterized and measured? It is important that measures of spatial knowledge accurately capture a person's representations of his or her spatial experience. Thus, spatial measures depend on the theoretical characterization of spatial knowledge. The main goal of my thesis is to examine alternative methods for measuring memory of spatial configural knowledge based on alternative characterizations of spatial knowledge representations.

Spatial Knowledge

Spatial knowledge is the cognitive ability to determine, understand, and remember relationships between objects and locations within an environment. This concept refers to the subset of people's knowledge that represents their immediate or remote environmental space (Denis, 1997). Seigel and White (1975) classified spatial knowledge into three major categories. They proposed that people can acquire three types of spatial knowledge through direct experience with their environment: landmark knowledge, route knowledge, and survey knowledge. The contemporary term for survey knowledge is *configural knowledge*, and configural knowledge is the term used in this thesis. Seigel and White's developmental three-stage theory also assumed that spatial knowledge developed in ontogenetic, sequential stages; learning was incremental and configural spatial knowledge was absorbed over time with repeated environmental exposure. According to this three-stage theory, landmark knowledge is acquired first, followed by route knowledge and then configural knowledge.

Landmark spatial knowledge. A landmark can be considered anything within the environment that is sufficiently distinctive to serve as a relatively unique reference. This includes buildings with structural or symbolic uniqueness, and smaller distinctive items within a larger environment. People have landmark knowledge when they know that one or more landmarks are in a region and they can recognize them. Landmark knowledge allows people to know when they are near to other objects in a region. Landmarks also are important components of both route and configural knowledge.

Landmarks fall into two general categories, global and local (Gillner & Mallot, 1998; Ruddle & Péruch, 2004). Landmarks are *global* when they can be seen from many different and distant locations or regions within an environment. For example, suppose the goal is to navigate to a target such as Memorial Hall in downtown Dayton, Ohio. A global landmark could be Kettering Tower. This building is the tallest building in Dayton and is visible from most areas surrounding the city. It would be helpful in getting you to the general downtown area, where Memorial Hall is located. *Local* landmarks can only be seen when a person is near the landmark. Examples of local landmarks are small buildings or areas, shops or signs, unique design elements inside or outside of buildings, and even objects in a room. The key feature is the distinctiveness that can be easily identified by the person navigating in the environment. For example, River Scape on Monument Avenue in downtown Dayton, Ohio is both a distinctive and symbolically unique small park that could be used as a local landmark. It is just a few blocks away from Memorial Hall. Therefore, if you are near River Scape, you may know you are near Memorial Hall.

Route spatial knowledge. If a person knows a set of actions to get from location A to location B, then he or she knows a *route* from A to B. Thus, route knowledge consists of procedures, a sequence of steps that will move a person to the target location. It describes where a navigator should change direction and what action should be taken at these choice points (Thorndyke & Hayes-Roth, 1982). For example, simple route knowledge can be described in linguistic spatial terms such as "Turn right when you reach River Scape." Route knowledge can also be a description of the path a navigator will take, such as "Drive down First Street and it will take you to Memorial Hall." Route knowledge can be acquired through personal self-navigation or it can be acquired socially through written or oral descriptions.

Configural spatial knowledge. The third category of spatial knowledge is the most abstract. Configural knowledge refers to the spatial understanding of objects and locations in relation to each other – their configuration in space. It is a map-like representation of an area or region. People know where objects or locations are spatially located in relation to each other. They have information about angular relations and relative straight-line distances. Configural knowledge, as a cognitive process, reflects an understanding of spatial layout. In contrast to the procedural nature of route knowledge, configural knowledge provides a declarative understanding of where you are in a region, whether it is in your neighborhood, your city, or your office building (Colle & Reid, 2003; Kirasic, Allen, & Seigel, 1984).

Configural spatial knowledge can emerge from directly experiencing an environment or from using navigational aids, such as maps. Although configural and survey knowledge are typically used as synonymous terms, if a distinction between the two terms is to be made, survey knowledge is more likely to refer to information obtained from a map and configural knowledge is more likely to refer to information obtained from direct experience.

Early spatial researchers suggested repeated exposure to an environment led to more accurate spatial representations of that environment. These findings were interpreted as a qualitative shift in the representation of space from route knowledge to configural knowledge (Thorndyke & Hayes-Roth, 1982). Thorndyke and Hayes-Roth also suggested a theoretical distinction between landmark and route knowledge versus configural knowledge. This distinction considered the idea that landmark knowledge was acquired only to facilitate route knowledge, and that landmark knowledge was merely a subcategory of route knowledge. Landmark knowledge by itself did not serve any purpose and, therefore, did not exist as a separate spatial ability. Configural knowledge, on the other hand, was an abstract integration of both landmark and route knowledge, allowing for a more complex and flexible understanding of one's environment. Even though most of the spatial researchers in the last half-century have concluded that landmark, route, and configural knowledge are separate but interrelated knowledge states, current research studies generally look at the three spatial knowledge types separately (Colle & Reid, 1998, 2000, 2003; Denis, 1997; Foo, Warren, Duchon, & Tarr, 2005; Golledge, Ruggles, Pellegrino, & Gale, 1993; Kirasic et al., 1984; Montello, 1991; Presson, DeLange, & Hazelrigg, 1989; Rossano, West, & Robertson, 1999; Sadalla & Montello, 1989; Shelton & McNamara, 2004a).

In the field of spatial cognition, Siegel and White's (1975) three categories of spatial knowledge have generally been accepted, and cognitive research has certainly been aided by the theoretical descriptions of categories of spatial learning provided for by the developmental three-stage model. However, the assumption that configural knowledge acquisition depends on first acquiring route spatial knowledge has not. Configural spatial knowledge may be acquired rapidly without first progressing through landmark and route knowledge stages, as assumed by the three-stage model (Colle & Reid, 1998; Gillner & Mallot, 1998; Maguire et al., 1998; Wolbers, Weiller, & Buchel, 2004). For example, research in our laboratory has shown that, under certain circumstances, accurate configural knowledge can emerge after one brief exposure to a virtual environment (Colle & Reid, 1998, 2000, 2003; Douglas & Colle, 2005). The example suggests that the theoretical underpinnings of configural knowledge and the nature of its representations are still inadequately specified.

Methods for Obtaining Spatial Experience.

Before spatial representation can be measured, participants must experience an environment so that they can acquire some spatial knowledge about it. Several different methods have been used to provide this experience.

Natural environments. Participants can directly interact with a physical environment by walking, driving or otherwise moving through it (McNamara, Rump, & Werner, 2003; McNamara & Shelton, 2003; Mou & McNamara, 2004; Sadalla & Montello, 1989; Sun, Chan, & Campos, 2004; Valiquette, McNamara, & Smith, 2003; Waller, Beall, & Loomis, 2004). Experience also has been provided by having experimental participants stand or sit stationary in a predetermined location so only their head and eyes can move (Burgess, Spiers, & Paleologou, 2004; Lehnung, Haaland, Pohl, & Leplow, 2001; Montello, 1991; Nori, Iachini, & Giusberti, 2004; Presson et al., 1989; Rieser, 1989; Shelton & McNamara, 2001, 2004a, 2004b; Thorndyke & Hayes-Roth, 1982).

Simulated dynamic displays. In dynamic displays, participants experience simulated movement through three-dimensional (3D) environments with perspective viewing and optical flow. These virtual environments can be either desktop or immersive displays, both of which provide changing perspectives from a moving viewpoint. Desktop displays refer to the 3D computer generated environments that are shown on computer monitors (Belingard & Péruch, 2000; Billinghurst & Weghorst, 1995; Chabanne, Péruch, & Thinus-Blanc, 2003; Colle & Reid, 1998, 2000, 2003; Foo et al., 2005; Lawton & Morrin, 1999; Maguire et al., 1998; Moffat, Hampson, & Hatzipantelis, 1998; Restat, Steck, Mochnatzki, & Mallot, 2004; Rossano & Moak, 1998; Rossano et al., 1999; Ruddle & Péruch, 2004; Sandstrom, Kaufman, & Huettel, 1998; Shelton & McNamara, 2004a; Sun et al., 2004; Waller et al., 2004; Werner & Schindler, 2004; Tlauka, Brolese, Pomeroy, & Hobbs, 2005; Wiener, Schnee, & Mallot, 2004; Witmer, Bailey, Knerr, & Parsons, 1996). Participants see a geometric perspective view on the monitor, but their complete field of view includes the environment beyond the monitor. Input devices such as a mouse, a joystick, a touchpad, or arrow keys control movement within the display.

Immersive displays. Immersive displays refer to displays in which a participants' field of view is completely occupied by the visual input provided by the display. Typically, rotational movements are coupled intrinsically with rotational movement in the display field of view. Externally controlled devices such as a mouse or arrow keys do not need to be used. Head-mounted displays are an example of an immersive display. In head-mounted displays, simulated scenes are linked to head movements so the environment remains stable overall, but the perspective changes when the wearer turns his or her head. For example, if a wearer turns their head to the right, he or she will be able to view the environment to the right, similar to what we see in a natural environment (Janzen, Schade, Katz, & Herrmann, 2001; Waller et al., 2004; Waller & Haun, 2003; Waller, Loomis, & Steck, 2003; Waller, Montello, Richardson, & Hegarty, 2002). However, this technology has limitations. A virtual field of view may be smaller than a person's normal field of view and visual display updates may lag behind head movements. Even with these limitations, virtual environments are experimentally advantageous because they allow for flexible experimental design and control not possible in most natural environments.

Static environments. Participants also can obtain spatial experience from artificial displays. Both static and dynamic displays have been used. Static environmental views include single photographs and 3D perspective views of geographic areas or locations. In static views, neither the participant nor the environment moves (Avraamides, Loomis, Klatzky, & Golledge, 2004; Diwadkar & McNamara, 1997; Hartley, Trinkler, & Burgess, 2004; Kozhevnikov & Hegarty, 2001; Maguire, Burgess, Donnett, Frackowiak, Frith, & O'Keefe, 1998; Mou & McNamara, 2002; Shelton & McNamara, 2001, 2004b; Tlauka, 2002). Another alternative is to have participants view multiple static views such as a series of photographs of an environment from several different perspectives (Diwadkar & McNamara, 1997; Iachini & Logie, 2003; Tlauka & Nairn, 2004). Using a series of static displays, researchers can simulate navigation. A viewer can virtually move through an environment by controlling a sequence of perspective views on hypertext markup language web pages (Couture, Colle, & Reid, 2005).

Map displays. Maps, or two-dimensional (2D) plan views of regions, neighborhoods, and buildings, also can provide people with static spatial knowledge of an environment (Kitchin, 1996; Presson et al., 1989; Rinck & Denis, 2004; Rossano et al., 1999; Ruddle, Payne, & Jones, 1997; Thompson, Valiquette, Bennett, & Sutherland, 1999; Shelton & McNamara, 2004b; Sun et al., 2004; Thorndyke & Hayes-Roth, 1982; Tlauka & Nairn, 2004). Maps can be used either as a primary source of environmental information or as a supplemental aid when navigating directly in a physical environment, for example, when using an in-vehicle navigation system while driving.

Environmental Experience and Spatial Knowledge Representations

Not all methods of gaining environmental experience seem to result in equivalent spatial knowledge representations. For example, research has shown that people learn spatial information from maps in an orientation specific manner. Directional estimates are made faster and more accurately when the judgments were aligned with the learned map than when direction judgments were not aligned with the learned map (Levine, Jankovic, & Pahj, M., 1982; Presson & Hazelrigg, 1984). However, perspective viewing of both natural and virtual environments have not reliably resulted in orientation specific performance decrements (Evans & Pezdek, 1980; Nori, Grandicelli, & Giusberti, 2006, Tlauka, 2006, Thorndyke & Hayes-Roth, 1982).

In the present experiment participants gained spatial experience using a 3D virtual environment because there is evidence that spatial knowledge representations acquired from virtual environments are comparable to representations gained from natural environments (Ruddle et al., 1997; Waller et al., 2004; Witmer et al., 1996). For example, Witmer et al. (1996) compared learning from a virtual versus a natural physical environment using a large office building. Participants practiced by either navigating in a virtual model of the office building or in the building itself. A projective convergence test, a recall measure used to assess both direction and distance, was used to measure configural knowledge. There were no statistically significant differences in configural spatial learning between the virtual and physical environment groups.

Measurement Models of Configural Spatial Representation

Measures of configural spatial knowledge acquisition attempt to probe memory to determine the nature of the representations that were stored based on the experience in the environment. Configural knowledge is sometimes measured by asking people to reproduce environmental angles. For these measurement methods to be valid, it is important that measures of spatial knowledge accurately capture a person's representations of his or her spatial experience. The models underlying these measures often are not specified explicitly. However, the methods of measurement do imply underlying models of configural spatial representation. Two different models underlying the measurement methods used in this thesis are the quasi-Euclidean model and the object reference model.

Quasi-Euclidean model. The quasi-Euclidean model underlies a typical approach to the measurement of configural spatial knowledge. Spatial knowledge is represented analogously to a plan view mental map, a 2D layout of points in spaces. In plane geometry the basic elements are points in space and lines connecting points. Two points define a line. Two connected lines form an angle so that at least three points with connecting lines are needed in order to form an angle in this geometric space. If cognitive spatial representations have the same basic elements, then measures must capture them. Therefore, queries asking people to reproduce environmental angles are framed using objects in three environmental locations, consistent with the assumptions of the quasi-Euclidean model. An example of a quasi-Euclidean query is "You are <u>at</u> Kettering Tower, <u>facing</u> toward River Scape, point to <u>Memorial Hall</u>." Note that the query is described in terms of three points in space, the current location you are standing *at*, the location of the object you are *facing*, and the location of the *target* object.

Object reference model. An alternative model underlying methods of measuring the acquisition of configural spatial knowledge is an object reference model of spatial representation. The object reference model does not assume that people's spatial knowledge representations are a set of points in space. Instead, it assumes that people think about space in terms of objects that have substance, extension, and, usually, distinguishable sides. These objects intrinsically have size and angular orientation with identifiable fronts or faces. Therefore, two objects can be angularly related to each other. For example, the front façade of one building can be across the street and facing the façade of another building. Three points are not needed to describe this angular relationship. The “space” of these spatial relationships is populated with relationships between solid objects, not with dimensionless points in a geometric vacuum. The object reference model considers that the size, shape, orientation and recognizable faces of environmental objects are stored in spatial memory. People use these characteristics to determine angular relationships and relative distances. An example of an object reference query is “You are standing directly in front of *and* facing Kettering Tower, point to Memorial Hall.” Note that this query is described in terms of only two objects. Response depends on the observers being able to represent Kettering Tower as an object with an extended front and allows the observers to represent themselves in a perpendicular relationship to this front.

Methods for Measuring Configural Knowledge

To measure configural knowledge acquisition, participants first experience an environment to create spatial representations in memory. Following this experience, data are collected to evaluate participants’ memory. Acquired configural knowledge is assessed using two different retrieval tasks, pointing tasks and sketch maps. Pointing tasks require people to point from one object to another in response to queries about their locations in the environment. Pointing tasks have people point from one object to another in response to queries about their locations in the environment. Methods of collecting pointing data include having people point to objects or locations using a finger or by having them point indirectly using artificial devices such as a direction circle. The other retrieval task, sketch map drawing, allows researchers to visually evaluate a participants’ understanding of spatial relationships within the experienced environment.

Diverse methods have been used to score sketch maps to obtain quantitative indicators of spatial knowledge.

Pointing tasks. In studies of adults, people have been asked to point to environmental objects from memory. In addition, spatial knowledge has been measured by having participants stand at a location in a test environment and point to objects or other locations. Participants move their bodies or their heads to indicate direction to a target location. Both natural physical environments (Kirasic et al., 1984; Montello, 1991; Ruddle & Péruch, 2004; Tlauka, 2002; Waller et al., 2004; Wang & Brockmole, 2003) and virtual environments have been used (Ruddle & Péruch, 2004; Waller et al., 2002; Waller et al., 2004).

The ability to point to objects and estimate direction begins naturally and early in life. Conning and Byrne (1984), using a statically viewed environment, showed that the ability to spatially represent an environment develops at a very early age. In their study, participants as young as three years of age could understand and perform directional pointing judgments. Older children indicated the direction to several targets by pointing with a stick, showing a rudimentary understanding of spatial angles. Estimating directions in large-scale environments has been found to improve between the ages of seven and eleven (Curtis, Siegel, & Furlong, 1981). Herman, Heins, and Cohen (1987) showed that children can infer spatial relationships in a familiar environment by the age of six. These children were able to estimate direction to distant landmarks when they were tested from their homes. Lehnung et al. (2001) measured spatial knowledge in children (ages 5, 7, and 11) using both a finger-pointing task and a mechanical pointing

Figure 1. A typical direction circle. An example of a paper-based spatial knowledge measurement tool.

device. Her research showed that by age 11, children were as good at using a pointing device as they were at a finger-pointing task.

Direction circles. Given that older children and adults can use pointing devices as readily as finger pointing, spatial knowledge research employing adults subjects uses electronic or paper pointing devices to collect pointing data and assess spatial knowledge. Data are collected using a direction circle, a spatial knowledge measure that has been in use for nearly a century (Trowbridge, 1913). It is a 2D representation of space with elevation excluded, similar to a compass. Direction circles are used to respond to queries from the experimenter. Queries ask participants to point from memory to objects that were in the experienced environment.

Typically, a direction circle consists of both a larger, outer, circle with a small dot or circle in its center. Figure 1 illustrates a generic or typical direction circle. The outer circle is often referred to as the marking circle. Participants' imagined location is represented by the smaller, center circle. The direction the participant is facing is represented by a mark at the top (0/360°) of the circle. A participant's task is to place an indicator (e.g., a mark) on the outer circle to reflect the angle of a target object relative to his position at the center of the direction circle in response to a query such as "Where is Memorial Hall?" The direction circle is used in a wide variety of spatial tasks, including perspective tasks (Kozhevnikov & Hagerty, 2001; Mou & McNamara, 2002), projective convergence tasks (Curtis et al., 1981; Witmer et al., 1996), and configural knowledge tasks (Colle & Reid, 1998, 2000, 2003; Kirasic et al., 1984; Kozhevnikov & Hegarty, 2001; Kozlowski & Bryant, 1977; Rieser, 1989; Rossano & Moak, 1998; Rossano et al., 1999; McNamara et al., 2003; McNamara & Shelton, 2003; Ruddle et al., 1997; Ruddle & Péruch, 2004; Shelton & McNamara, 2004; Tlauka & Nairn, 2004; Waller et al., 2004; Witmer et al., 1996).

Traditional paper-based direction circles are easy to administer, convenient and portable. Shown on a piece of paper, participants use a pen or pencil to make a mark on the direction circle to indicate direction to a target object or location. Mechanical devices such as compasses have also been used as direction circles. Participants point to locations by controlling the pointer to indicate direction. Computer-based direction circles are another method used for indicating direction. Participants can make angular estimates directly on a computer displays using input devices such as a keyboard, a mouse, a joystick, or a touch screen.

Sketch Maps. Participants may be asked to sketch a map of the environment they experienced as a means of measuring configural spatial knowledge. Sketch maps may be drawn free-hand (Billinghurst & Weghorst, 1995; Colle & Reid, 1998, 2000, 2003;

Douglas & Colle, 2005; Gillner & Mallot, 1998; Janzen et al., 2001; Shelton & McNamara, 2004a; 2004b). Alternatively, pre-drawn maps of an environment may be used with participants filling in missing data or placing pre-cut shapes to indicate where objects were located (Kozlowski & Bryant, 1977; Rossano & Moak, 1998; Waller & Haun, 2003; Waller et al., 2003). A variety of map-scoring techniques have been employed to obtain quantitative measures of configural spatial knowledge.

Types of Spatial Pointing Judgments

Three different types of spatial judgments have been used to collect pointing data. Two of these judgments, judgments of relative direction and object-based judgments, use direction circles. The third type of judgment, immersively-cued judgments, uses an angular pointing judgment, but not a direction circle.

Judgment of relative direction. Judgments of relative direction, or JRDs, are commonly used to collect spatial knowledge using direction circles (Golledge et al., 1993; Kitchin, 1996; Kozhevnikov & Hegarty, 2001; McNamara, 1986; Rossano & Moak, 1998; Rossano et al., 1999; Tversky, 1981; Witmer et al., 1996). A JRD judgment is made in response to a query of the form "You are standing at Kettering Tower facing River Scape. Point to Memorial Hall." Note that the JRD judgment refers to three points in space – the location one is standing at (*s*), the location one is facing (*f*), and the location of the target (*t*). Thus, a JRD judgment is consistent with the quasi-Euclidean model, described earlier. According to the quasi-Euclidean model, three distinct points in space are needed to form an angle. JRD judgments are consistent with this assumption. A JRD judgment requires participants to focus on these three locations in order to determine relative direction.

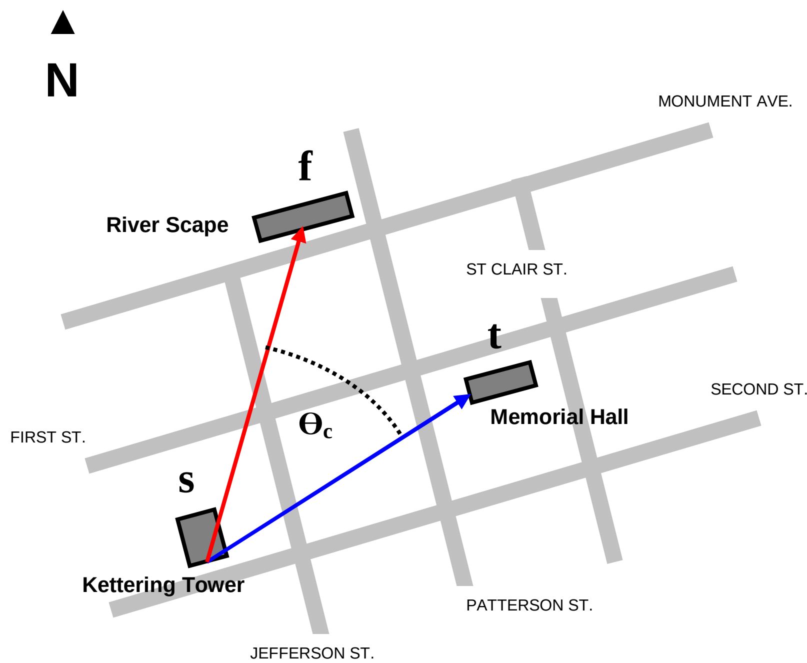


Figure 2. Graphical representation of a *Judgment of Relative Direction*, or JRD. The participant is standing at the Kettering Tower, facing River Scape, and pointing to Memorial Hall.

For the purposed of this study, a JRD judgment will also be referred to as an *s-f-t* judgment.

A JRD judgment is illustrated in Figure 2. It shows a person at standing at the Kettering Tower (*s*), facing River Scape (*f*), and the correct pointing direction to the target (*t*), Memorial Hall. Figure 3 shows how this layout might be represented on a direction circle. The error measure, or absolute value of the difference between the participants' estimated, or response angle (Θ_r) and the correct angle (Θ_c), is represented by the formula $|\Theta_r-\Theta_c|$.

Object-based judgment. Recently, Colle and Reid (1998, 2000, 2003) used an alternative spatial knowledge measure called an OBJ, or *object-based judgment.* This

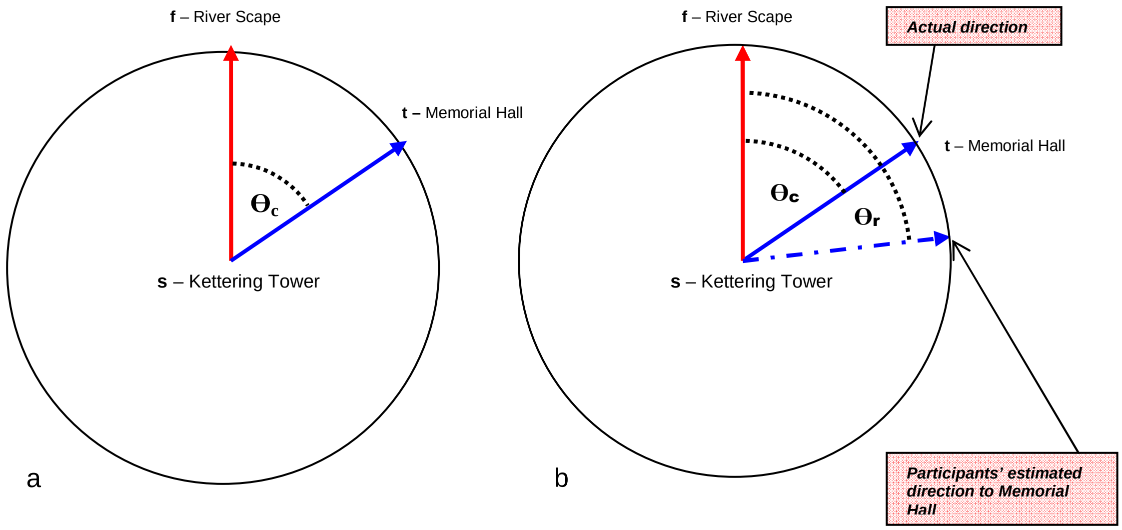


Figure 3. Mathematical representation of a JRD. (a) The correct or target angle (Θ_c) to Memorial Hall shown on a direction circle; (b) Θ_r is the participant's response, or directional estimate.

judgment is based on the assumptions of the object reference model. If people remember objects including their shape, façade and orientation, then these aspects can be used to form judgment queries. An OBJ judgment has the form "You are standing in front of and facing Kettering Tower. Point to Memorial Hall." People are asked to imagine the front of the building and to imagine themselves relative, and perpendicular, to it. Thus, the building has substance and an extended front surface. It is not just a point in space. The geometry of an OBJ judgment is shown in Figure 4. Memorial Hall is still the target (*t*), but River Scape is eliminated as a variable, and Kettering Tower effectively becomes both (*s*) and (*f*). The correct angle measure, Θ_c is between Kettering Tower and Memorial Hall, but the apex has become the participant standing in front of Kettering Tower and the perpendicular line that runs through the front facing portion of this building.

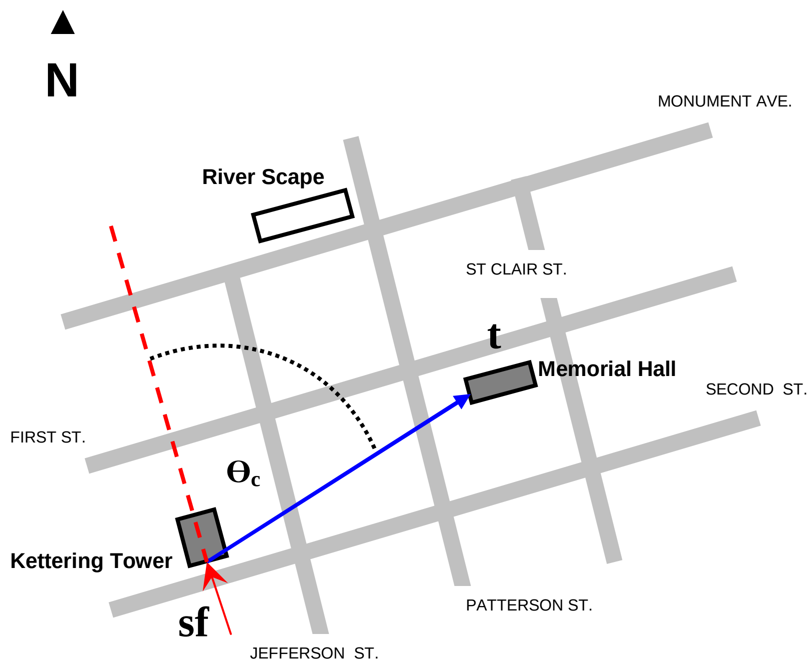


Figure 4. Graphic representation of an *Object-Based Judgment*, or OBJ. The participant is standing in front of and facing Kettering Tower and pointing to Memorial Hall.

Figure 5 shows how this OBJ judgment might be correctly represented on a direction circle. The correct angle Θ_c is between the perpendicular line from the participant to the front of Kettering Tower and the line created by the direction to Memorial Hall. The entered response, Θ_r, is shown along with Θ_c for comparison. The measure of error again is the absolute value of the difference between the response angle and the correct angle, $|\Theta_r-\Theta_c|$. A person need only imagine himself or herself as close to and facing (*f*). The facing direction is intrinsically related to the standing at location (*s*). The participant can define the relationship between (*f*) and (*t*) based on his or her own perspective as part of this relationship. The *s*-*f* part of a JRD *s*-*f*-*t* relationship

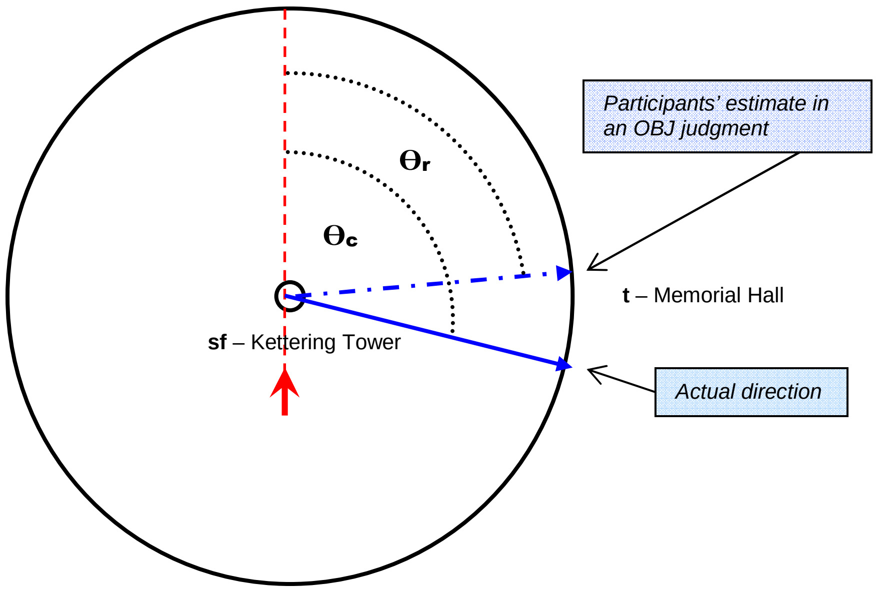


Figure 5. Mathematical representation of an OBJ. Θ_c is the correct angle to Memorial Hall; Θ_r is the participant's response or directional estimate.

becomes *sf*, creating the new relation *sf*-*t*. For the purposed of this study, an OBJ judgment will also be referred to as an *sf*-*t* judgment.

Immersively-cued judgment. The third type of judgment is the *immersively-cued judgment*, or ICJ (Waller et al., 2004). *Immersively* refers to the fact that a person is immersed in the environment during the test phase and at least part of the environment is visible, providing direct visual cues about the environment. Because of this, an ICJ judgment can only be obtained with the participant physically in the natural world or present in the virtual environment. To make an ICJ judgment, a participant is placed at a designed point in space, facing a predetermined but arbitrary direction. The participant is asked to turn toward an unseen target object or location (*t*). An example of an ICJ judgment would be "You are standing at Kettering Tower, turn to Memorial Hall." Since the person is not given clarification about their relationship to Kettering Tower, this particular situation might assume a quasi-Euclidean theoretical model. However, the person can see Kettering Tower and has other direct visual cues about many objects within the environment near it and could be making decisions about orientation and spatial relationships based on an object reference model of spatial representation. Consequently, an ICJ judgment is consistent with both models, and cannot be used to differentiate between them.

Figure 6 shows an ICJ judgment using the downtown Dayton example "You are standing at Kettering Tower, turn to Memorial Hall." The participant is placed so that he or she is standing at Kettering Tower, facing a predetermined direction (e.g., River Scape). The red (dotted) arrow represents the direction the participant would be facing when placed in the environment. The facing location (*f*) is not an explicit part of the

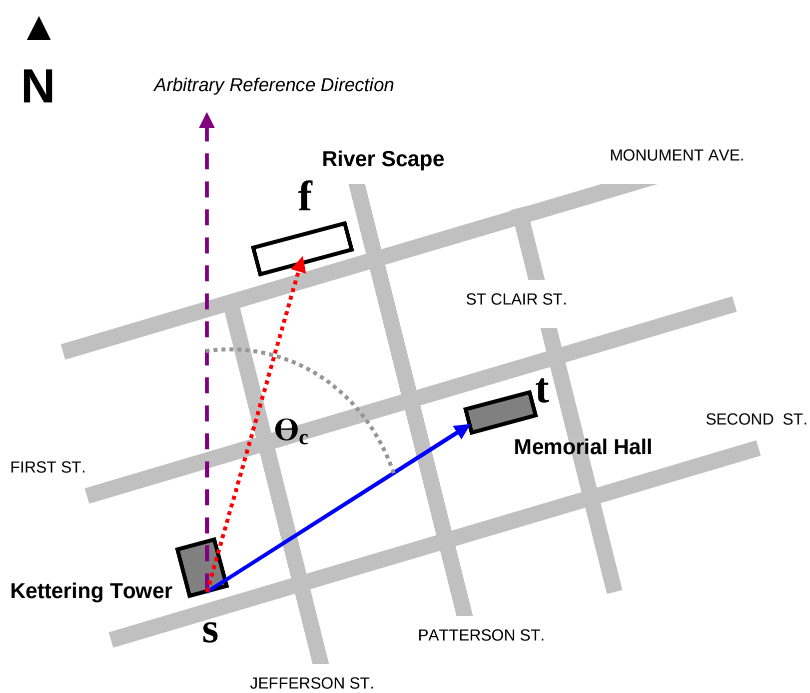


Figure 6. Graphic representation of an *Immersively-cued Judgment,* or ICJ. The participant is facing in the direction of River Scape and turns to face Memorial Hall.

judgment. For an ICJ memory judgment, Memorial Hall must not be visible from the standing at location (*s*). Angular error for an ICJ judgment is determined by an arbitrary reference direction, similar to a bearing estimate. The purple (dashed) arrow represents the reference direction of North that is used to determine the correct target angle Θ_c. An illustration of an ICJ judgment represented on a direction circle is shown in Figure 7. The correct angle is shown as Θ_c. The response angle (Θ_r) is also referenced to the arbitrary facing direction. Angular error measure is determined by $|\Theta_r - \Theta_c|$, just like the JRD and OBJ judgment.

ICJ judgments can also be made in natural physical environments without the aid of head-mounted displays or other virtual environments. Without technology, researchers place participants in a natural environment and assess directional knowledge for unseen

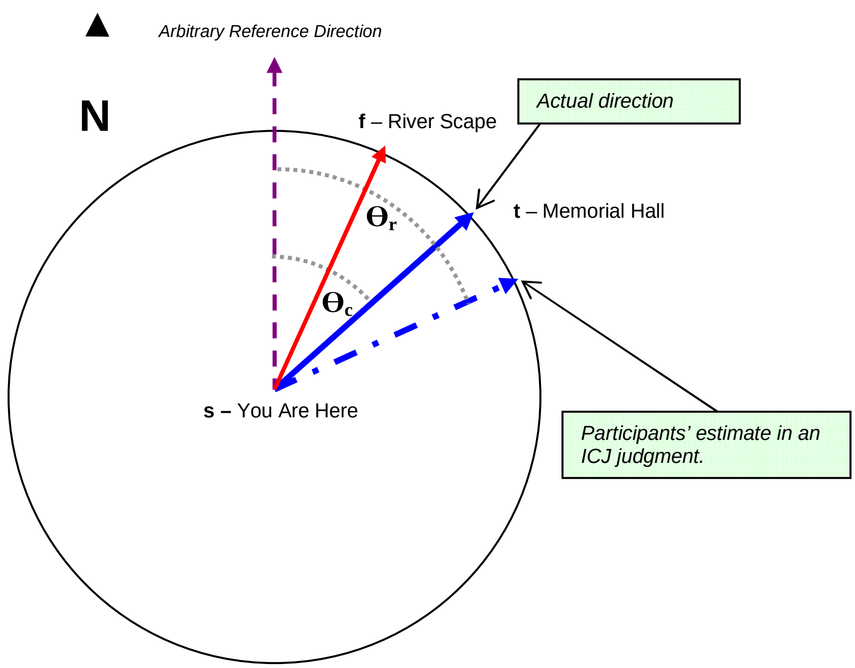


Figure 7. Mathematical representation of an ICJ. Θ_c is the correct angle to Memorial Hall; Θ_r is the participant's response, or directional estimate.

targets (Chabanne et al., 2003; Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002; Kirasic et al., 1984; Montello, 1991; Ruddle & Péruch, 2004; Tlauka, 2002; Witmer et al., 1996). Because of the need to represent the environment realistically, tests using ICJ judgments in both natural and virtual environments are more difficult than tests with JRD or OBJ direction circles.

Waller et al. (2004) found directional estimates of locations were improved when their participants made ICJ judgments wearing a head-mounted display (HMD) compared to JRD judgments. They argued that ICJ judgments were a better measure of configural knowledge than the traditional direction circle measure using JRD judgments. Their HMD condition had participants virtually stand at various locations on the campus of the University of in Santa Barbara. The HMD allowed the participants to see and experience the predetermined test locations. Researchers asked participants to physically turn their head toward an unseen target location. Wearing the HMD, participants turned their head toward the target, which caused the virtual environment to rotate with them. The HMD computer program recorded the participants' estimate of the direction to the target location via the rotation of their head to the target direction. They found that angular error was smaller for the ICJ judgments than angular error obtained for a group of students who made JRD judgments.

Waller et al. (2004) suggested the improved performance with ICJ judgments may have been facilitated by the salient geometric cues available to participants when they were tested in the environment. However, when people are located in the environment during the test phase, object reference stimuli are also available to them. So it is possible the improved performance with ICJ judgments was the result of utilizing intrinsic object relationships to make directional estimates, much like OBJ judgments. Consequently, ICJ judgments do not discriminate between the quasi-Euclidean and object reference models because ICJ directional estimates could be implicitly making use of the mechanisms inherent to either JRD or OBJ judgments.

Configural Measurement from Sketch Maps

Sketch maps are another method for measuring configural spatial knowledge. They offer an alternative evaluation of a person's spatial representation of an environment. Although sketch maps and pointing tasks are considered different behavioral acts, they should both be based on the same previously-acquired spatial knowledge representations. For that reason, they should both be valid measures of configural spatial knowledge. Minimally they should produce the same pattern of results.

Sketch maps have been scored using goodness ratings, number of features included, route length relationships, or checklists of features (Coluccia, Bosco, & Brandimonte, 2007; Gillner & Mallot, 1998; Kitchin, 1996; Kozlowski & Bryant, 1977; Lynch, 1960; Rossano & Moak, 1998; Waller & Haun, 2003; Waller et al., 2003). However, Colle and Reid (1998) introduced an alternative technique for scoring sketch maps, a scoring technique that asks the sketch map "pointing" queries. This analytic technique has been used with OBJ queries, but it also can be used with JRD queries. For example, absolute angular error can be calculated for the JRD query "You are standing at Kettering Tower facing River Scape, point to Memorial Hall," as well as for the OBJ query "You are standing in front of and facing Kettering Tower, point to Memorial Hall."

A sketch map is created by a participant to reflect his or her memory of the spatial relationships in the experienced environment. However, the scoring of sketch maps makes assumptions about participants underlying spatial memory representations. For example, *how* these maps are scored could reflect the underlying assumptions of either the quasi-Euclidean or the object reference model of spatial representation. Maps can be scored to be consistent with the quasi-Euclidean model (JRD queries to the sketch map) or the object reference model (OBJ queries to the sketch map), or both.

Theoretically, map scores should be predictive of how people mentally represent space and should correspond with pointing task measures. If the quasi-Euclidean model accurately reflects a persons' acquired configural knowledge of an environment, then JRD map scores should produce lower absolute angular error than OBJ map scores, consistent with the predictions of the results obtained with the pointing tasks. If the object reference model is more representative of a persons' acquired configural spatial knowledge, then the OBJ map scores should produce lower absolute angular error than JRD map scores, consistent with the predictions of the results obtained with the pointing tasks. Thus, sketch maps should provide a converging measure of configural spatial knowledge with pointing tasks, and provide additional tests of the predictions of the underlying measurement models.

Hypotheses

A major goal of spatial research is to understand how people mentally represent environments. As discussed earlier, the two models of spatial representation – the quasi-Euclidean model and the object reference model – differ in their assumptions about these memory representations. First, the quasi-Euclidean model assumes people think about and remember environments in terms of points in space. Objects are just labels for environmental points. In contrast, the object reference model assumes people think about space in terms of objects with substance, orientation, and relationships to other objects.

As described above, a JRD judgment follows from the assumptions of the quasi-Euclidean measurement model and an OBJ judgment follows from the assumptions the object reference measurement model. If spatial judgments are reflective of how people mentally represent their environment, then the validity of the underlying measurement models can be evaluated by examining the accuracy of the two types of judgments.

In evaluating pointing task data, if absolute angular error is smaller for JRD judgments than for OBJ judgments, the data support the quasi-Euclidean model. However, if error is smaller for OBJ judgments than for JRD judgments, then the data support the object reference model. This prediction is clearest for angular error data, but it would also be consistent with other measures such as judgment confidence and latency of response, two additional pointing task measures obtained in this experiment.

Data from sketch maps is important because of the assumptions of the measurement models. Both models assume that performance is based on underlying memory representations, not performance due exclusively to effectiveness of retrieval of the spatial information. Actions needed to sketch maps of a directly perceived environment are different than those needed to respond to pointing queries. For example, map sketching suggests that people take a plan view perspective, or allocentric perspective, of the environment. People directly relate each sketched object to other objects previously sketched. In contrast, a pointing task only requires participants to consider the object locations mentioned in a query and then make a simple pointing response on a direction circle. Retrieval needed to answer these queries appears to be based on taking an egocentric view of the environment. Thus, sketch maps are an alternative means of tapping spatial memory information. Sketch map data also were collected in this experiment.

To evaluate a participant's sketch map, the map itself can be asked JRD or OBJ queries, or both. If sketch maps are based on the quasi-Euclidean model, then JRD query scores should be more accurate than OBJ query scores. If sketch maps are based on the object reference model, then OBJ query scores should be more accurate than JRD query scores. Thus, sketch map and pointing task measurements provide convergent validity for the empirical tests of the measurement models of the underlying spatial representations. If performance is based on spatial memory representations, and not on retrieval mechanisms, then pointing and sketch map data should agree (converge).

Although absolute angular error data provide the clearest test of the two models, other indices from the pointing tasks may also reflect model characteristics, such as judgment confidence and latency to judgment response. Confidence should increase when judgment types are consistent with participants' spatial representations, providing a co-measure of acquired spatial knowledge. Latency to judgment – the time it takes to respond to a query – may be shorter when people are more confident of their judgments. Unlike reaction time measures, latency responses are not used as a direct measure of processing limitations. Instead, it is another potential correlated index of acquired spatial knowledge. Participants in the present study were unaware that their time to respond was being measured. Confidence and latency data should provide further convergent support for the angular accuracy data.

Methodological Issues

The central point of this thesis is to relate alternative pointing judgments to underlying measurement models and to use them to examine the validity of the models. Judgment types follow from different assumptions of how people represent space in memory. JRD judgments are consistent with the quasi-Euclidean model of spatial representation and OBJ judgments are consistent with the object reference model. Participants in this study were assigned to either a JRD judgment or an OBJ judgment condition. This between-subjects manipulation provided an overall comparison between the quasi-Euclidean and object reference models of spatial representation. In addition to judgment type, several variables were manipulated in this experiment for a more comprehensive comparison between the models of spatial representation.

Room effect. In previous research in our laboratory using desktop virtual environments of rooms connected by hallways, we found that configural spatial knowledge acquisition depended on the locations of the standing at (*s*) and target (*t*) locations (Colle & Reid, 1998, 2000, 2003; Douglas & Colle, 2005). After a brief experience in a virtual environment, mean absolute angular error of both OBJ judgments and OBJ measures taken from maps was smaller when (*s*) and (*t*) were in the same room (within-room), than it was when (*s*) was in one room and (*t*)was in a different room (between-room). This is called the room effect. Within-room configural spatial knowledge was acquired more rapidly than between-room configural spatial knowledge. Because these differences were found for studies involving OBJ judgments, JRD judgments were directly compared with OBJ judgments for both within-room and between-room queries in the present experiment.

The location of f. JRD and OBJ judgments both relate spatial knowledge of a target location (*t*) with reference to the imagined current location, the standing at location (*s*). But the location of the facing direction (*f*) may play an important role in the accuracy of a JRD judgment.

Besides their theoretical differences, JRD and OBJ judgments differ procedurally. JRD judgments make an explicit reference to the facing object (*f*) but OBJ judgments make no reference to (*f*). Methodologically, locations for the facing objects in JRD judgments needed to be selected. The locations of *f*, the facing objects, were systematically manipulated in this experiment. Half of the JRD judgments were made with (*s*) and (*f*) located in the same room (near-facing *f)*, and the other half of the JRD judgments were made with (*s*) and (*f*) located in different rooms (far-facing *f*). Again, both JRD and OBJ judgments were made using objects at the same standing at (*s*) and target locations (*t*). Comparisons were made separately for within-room queries (*s* and *t* in the same room) and for between-room queries (*s* and *t* in different rooms), because the room effect suggests that within-room spatial acquisition may differ from between-room spatial acquisition.

Matched angles. A comparison of JRD and OBJ judgments faces another potential methodological problem. The correct target angles for JRD judgments are not necessarily the same as those for corresponding OBJ judgments with the same (*s*) and (*t*) locations. This methodological problem is a consequence of the inherent differences in the facing direction for the JRD and OBJ judgment queries. A discrepancy in facing direction results in potentially differing correct target angles for JRD and OBJ judgments. The only case when JRD judgments have the same target angle as OBJ judgments is

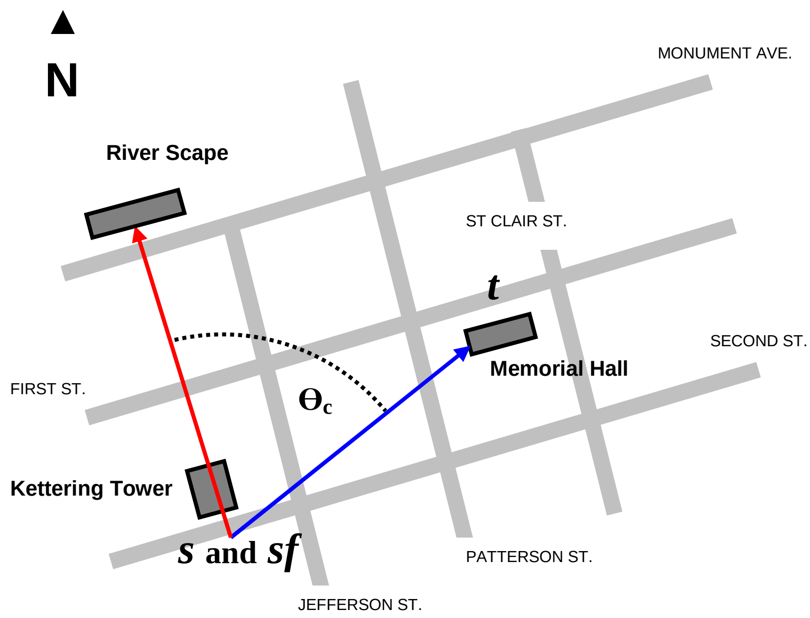


Figure 8. Graphic representation of a matched angle. Both JRD and OBJ participants are standing directly in front of and facing Kettering Tower, pointing to Memorial Hall.

when the facing direction (*f*) is straight ahead of the standing at object (*s*). If queries use these (*s*) and (*f*) objects, the results will be identical target angles for both JRD and OBJ judgments – *matched angles*. Figure 8 uses downtown Dayton (modified) to illustrate a matched angle. In this example, the participant is standing at or directly facing the south side of Kettering Tower. The location of River Scape is directly in front of (0°/360°) the standing at/directly facing position (*s* and *sf*). In a situation such as this, the standing at location (*s*) for a JRD judgment and the object orientation for an OBJ judgment are the same, so the target angle for both judgments (JRD or OBJ) would be identical.

In order to generalize the results for across angle types, subsets of matched and unmatched angles were both used in the experiment. Matched angles have the advantage of eliminating a potential confounding angular factor. However, using only matched angles could be problematic as it artificially restricts the object orientation in JRD judgments. Colle and Reid (1998) found that OBJ judgments did not depend on the target angles, but their analysis only equated angles in 90° quadrants.

Experimental Design

The overall experimental design was a 2 X 2 X 2 mixed factorial design with a between-subject factor of judgment (JRD, OBJ), and repeated-measures factors of room effect (within-room, between-room) and facing location (near-facing *f*, far-facing *f*). Absolute error, confidence of the judgment, and latency to make the judgment were the dependent variables for the pointing task. Angular error was the dependent variable for the sketch map data. Statistical analyses used a set of planned orthogonal contrasts instead of the standard factorial contrasts to evaluate the differences between JRD and OBJ judgments. The planned orthogonal contrasts are described in the results section.

II. METHOD

Participants

Participants were 17 male and 31 female students from an introductory psychology course at Wright State University who received course credit for participating. Age ranged from 18 to 27 (M = 20, SD = 2.23).

Simulated Environment

A simulated shopping center environment was created using the Morfit 3-D Engine. All participants experienced the same environment. Hallways measured 2.13 m wide. All walls had a textured light bluish-green surface. Ceilings were a textured white color and floors were wood-colored parquet. Object textures were obtained from digital photographs of real objects. To render objects, we constructed appropriately sized frames and pasted textures on their viewable surfaces. Doorways were always open. The navigational viewpoint was horizontal at a simulated eye height of 1.52 m. Horizontal and vertical geometric fields of view were 90° and 75° respectively. Participants navigated the simulated environment via arrow keys on a keyboard. The up and down arrows moved the viewpoint forward or backward 91 cm. Pressing the right and left arrow keys rotated the viewpoint, clockwise or counter-clockwise, by 3°. Appropriate optic flow was generated by movement in the environment.

Pointing data was collected on a touch screen monitor. The screen measured 17.8 cm high by 24.1 cm wide. The background color of the monitor was white. A direction circle, a blue bi-colored segmented circle, was displayed in the center of the monitor. A small dot in the center of the large circle represented the participants' imagined body position within the environment. Figure 9 shows a screen capture of the touch screen monitor direction circle. Participants touched the small center dot to initiate a trial. A judgment query appeared at the top of screen and participants indicated the pointing angle by touching an area on or near the outer circle.

Figure 10 shows the layout of the simulated environment, which consisted of five rooms in an inverted U-shaped configuration. One room simulated an employee office, another room simulated a vending machine area and the other three rooms were simulated retail stores. There was an appliance store, an electronics store, and a furniture store. Each room or store contained four task objects. A set of lockers, a phone, an

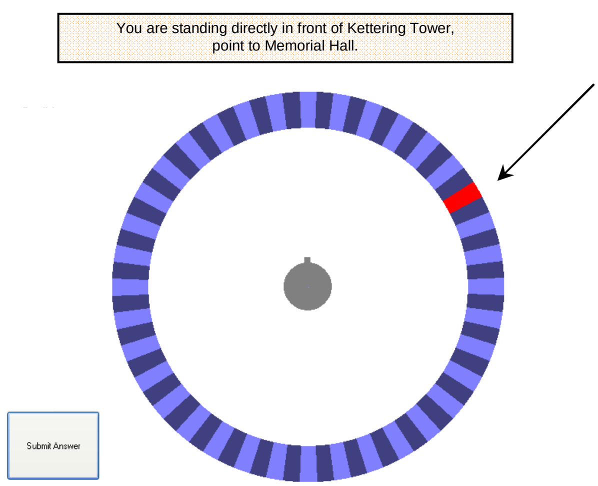


Figure 9. Computer-based direction circle. The blue squares turn red when a participant touches the screen to make an angular estimate.

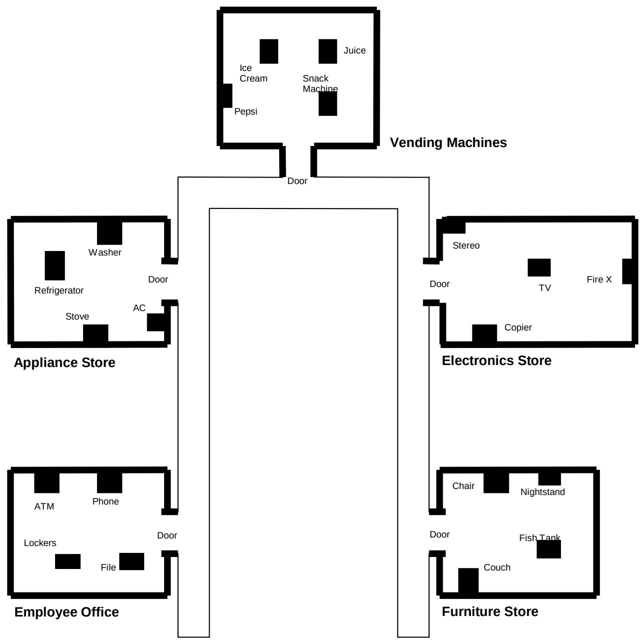


Figure 10. Plan view of simulated environment.

ATM, and a file cabinet were located in the employee office. A snack machine, juice machine, Pepsi machine, and ice cream machine were located in the vending machine area. A washing machine, a refrigerator, a stove, and an air conditioner were located in the appliance store. A stereo, a copy machine, a fire extinguisher and a TV were located in the electronics store. A table, a chair, a fish tank, and a couch were located in the furniture store. Figure 11 shows a screen shot of the inside of the vending machine area.

Procedure

Participants navigated through the environment while acting the role of an employee hired to take inventory of all the items in the shopping center. Participants followed a scripted scenario in which they were instructed to locate a task object and to navigate to the object until they were standing in front of and about an arm’s length

Figure 11. Screen capture of virtual environment. The four task objects and the doorway inside the vending machine area.

away. Once each task was complete, participants were given the next task object. All participants visited the five rooms in the following order: employee office, appliance store, vending machine area, electronics store, and furniture store. All participants navigated to the task objects in the same order. A written version of the navigation scenario can be found in Appendix A. In Figure 12, the small red number next to each task object denotes the visitation order. For example, the 1 next to the lockers indicates that participants visited the lockers first. The 15 next to the stereo indicates that from 1-20, the stereo was the 15th task object. Time to complete the shopping tasks was approximately 25 min.

Spatial knowledge was evaluated using a pointing task that included either JRD judgments or OBJ judgments, and a sketch map task in counterbalanced order across participants. Pointing instructions were phrased differently for the JRD and OBJ judgments. Instructions for the pointing task are found in Appendices B and C.

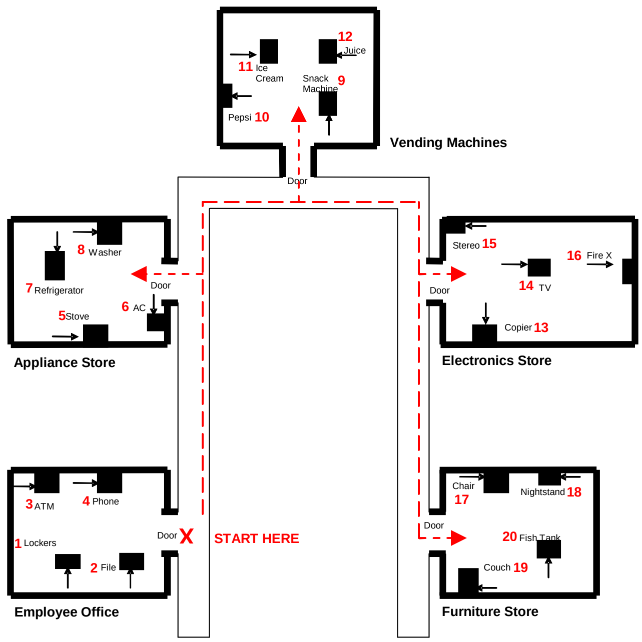


Figure 12. Navigation path and task object order. The black arrows indicate the front face of each task object.

Pointing task. To make direction circle judgments, participants were instructed to press the center dot when they were ready to see the judgment query for trial 1. Depending on a participants' judgment condition, he or she would next see either a JRD query or an OBJ query. Queries were displayed when the center dot was pressed. A timing clock started when the center dot was touched. Participants lifted their finger from the center dot and touched the outer circle to indicate the angle to the target. Participants could change their response by touching on another part of the circle. The direction circle was segmented into 5° arcs. Preliminary testing in the lab showed 5° segment sizes can be touched reliably.

Angular responses were recorded with 0° (top of direction circle) as a referent. Angular error for each response was calculated by taking absolute value of the difference between the response angle and the target angle. Only the shortest distance was used.

Thus, the Excel® computational formula is MIN[ABS(Θ_r -Θ_c), 360-ABS(Θ_r -Θ_c)]. Latency data from onset included time of lift-off from center location to time until both first and last outer circle responses. Response times were cumulative and all touch responses (not just the correct response) were included in the analysis. To complete a trial, participants touched a designated *Submit Answer* icon. Confidence data was collected after each trial. Once the participant pressed the *Submit Answer* icon, they were asked how confident they were that their response was correct. The confidence data was based on a 7-point scale, with 7 being "completely confident" that their response was correct, and 1 being "completely unconfident" that their response was correct.

Each participant received 16 within-room judgments and 16 between-room judgments. The computer program randomly shuffled judgment queries for each participant. Half of the JRD judgment within-room queries were near-facing judgments, with (*s*) and (*f*) in the same room; half were far-facing judgments with (*s*) and (*f*) in different rooms. As discussed earlier, every JRD judgment had a corresponding OBJ judgment (yoked) so that every JRD judgment standing at location (*s*) and target location

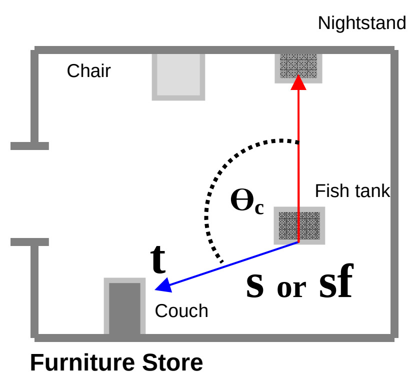


Figure 13. A *matched angle* query. The fish tank can be either *s* or *sf*, depending on the judgment. Since both participants have the same directional orientation for the query, the resulting target angle is the same.

(t) corresponded to an OBJ judgment with the exact same (s) and (t).

The test environment was designed so half of the within-room and between-room queries (eight of 16) could be matched target angles. To reiterate, (s) and (f) must be linearly related in order to achieve matched target angles. Figure 13 shows an example of a matched angle query in the test environment. Here, the fish tank could be either *s* or *sf*, depending on the judgment used. The JRD judgment, “You are standing at the fish tank facing the nightstand, point to the couch”, and the corresponding OBJ judgment, “You are standing in front of and facing the fish tank. Point to the couch”, produce the same target angle. A list of JRD and OBJ queries, including matched angle queries, can be found in Appendix D.

Correct target angles were segmented into four quadrants. Quadrants were operationally defined as front, right, back, and left, which correspond to angles (335° - 45°), (45° - 135°), (135° - 225°), and (225° - 335°) respectively. Correct target angles were balanced across quadrants within each of the four cells of the factorial design, meaning quadrants were used equally often. Correct target angles are also listed in Appendix D.

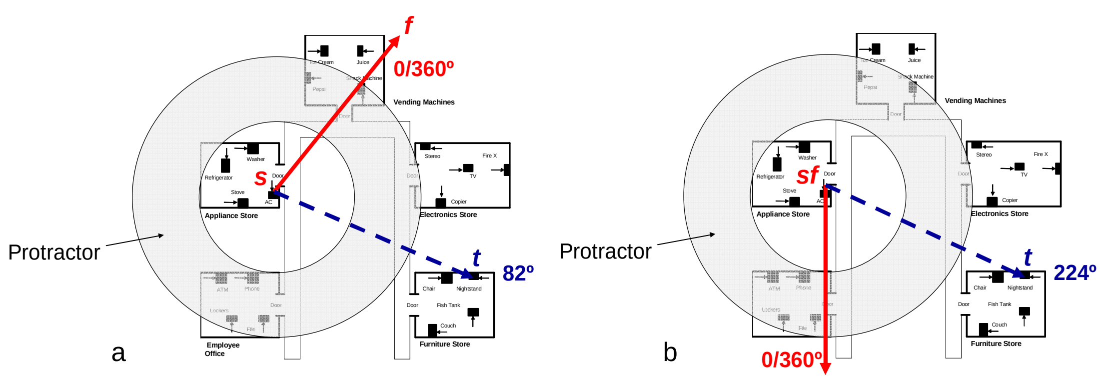


Figure 14. Scoring sketch maps. To measure angular relationships, zero on the protractor is aligned either with the facing direction for a JRD query (a), or perpendicular to the front face of the task object for an OBJ query (b).

Sketch maps. Along with pointing data, and in counterbalanced order, each participant drew a sketch map. The free-hand sketch maps showed a plan view of the shopping center and included all the rooms, stores and objects that the participant visited. Participants labeled each task object and drew an arrow to indicate the front face of each task (the black arrows in Figure 12 indicate the front face of each task object). The instructions for drawing sketching maps can be found in Appendix E.

Configural error, or map accuracy, was calculated by laying a clear protractor on top of the map. Figure 14 shows that when the protractor was placed over the standing at object (*s*), with 0° aimed either toward the facing location (*f*) (for JRD judgments), or perpendicular to the task object's front face (for OBJ judgments), the resulting angle from 0° to the target (*t*) could be determined. This angle was entered into data files to be analyzed like the pointing data, Excel® MIN[ABS(Θ_r -Θ_c), 360-ABS(Θ_r -Θ_c)].

III. RESULTS

This experiment was a 2 X 2 X 2 mixed factorial design with a between-subject factor of judgment (JRD, OBJ), and repeated-measures factors of room effect (within-room, between-room) and facing object (*f*) location (near-facing *f*, far-facing *f*). However, this experimental design was analyzed using a different set of seven orthogonal contrasts. The main effects of judgment type and room effect and their interaction from the factorial ANOVA were kept as contrasts. The main effects are shown as contrasts 1 and 2 in the top two rows of Table 1. Contrast 5 in row 5 is the judgment by room effect interaction. Two other contrasts analyzed facing object location (*f*-location) separately for each level of the room effect (within-room, between-room). Contrast 3, shown in row 3 of Table 1, analyzes the location of the facing object (*f*) for within-room judgment queries (within *f*), and contrast 4, shown in row 4, analyzes the location of the facing object (*f*) for between-room judgment queries (between *f*). Contrasts 6 and 7, shown in rows 6 and 7, show the interactions of judgment type with contrasts 3 and 4, respectively. All dependent variables were analyzed using the same seven contrasts. As discussed earlier, the data were analyzed using both the entire data set and the subset of data with matched angles. A 5% level of confidence was used for all statistical decisions.

Table 1

Planned Orthogonal Contrasts

	JRD				OBJ			
	Within-room		Between-room		Within-room		Between-room	
Contrast	Near-facing	Far-facing	Near-facing	Far-facing	Near-facing	Far-facing	Near-facing	Far-facing
1 Judgment	1	1	1	1	-1	-1	-1	-1
2 Room Effect	1	1	-1	-1	1	1	-1	1
3 Within (*f*)	1	-1	0	0	1	-1	0	0
4 Between (*f*)	0	0	1	-1	0	0	1	-1
Interactions with Judgment								
5 Judgment x Room	1	1	-1	-1	-1	-1	1	-1
6 Judgment x Within	1	-1	0	0	-1	1	0	0
7 Judgment x Between	0	0	1	-1	0	0	-1	1

Note. These contrasts are different than those associated with the 2 x 2 x 2 standard factorial design.

Pointing Data

Angular error. As expected from previous research (Colle & Reid, 1998, 2000; Douglas & Colle, 2005), there was a significant room effect. Contrast 2 was $F(1,46) = 102.17$, $MSE = 377.21$, $p < .0001$. As Figure 15 shows, mean angular error was greater for between-room than for within-room queries. Mean angular error for within-room queries of was 53.0°, compared to 81.4° for between-room queries. Figure 15 also shows that the room effect was larger for OBJ than for JRD judgments. The judgment by room effect (contrast 5) was statistically significant, $F(1,46) = 21.73$, $MSE = 377.21$, $p = .0001$. Importantly, OBJ judgments produced considerably less angular error when the query was within-room, having a mean angular error of 41.7° compared to 64.4° for the JRD

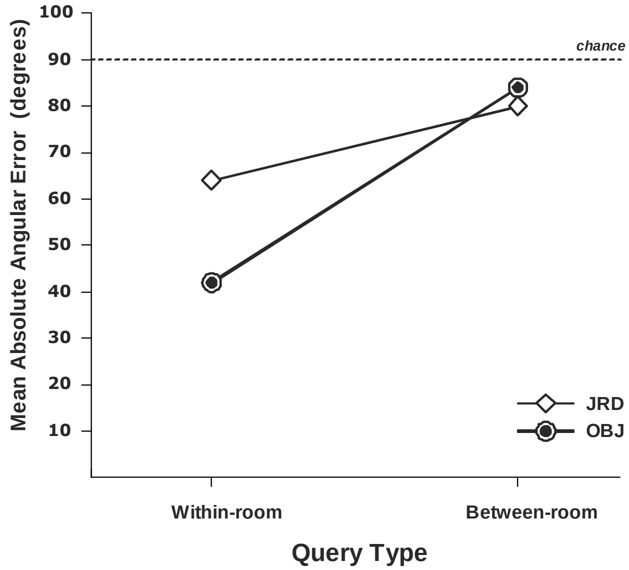


Figure 15. Angular error results for the room effect – full data set.

judgment. OBJ and JRD judgments produced similar results for between-room queries. There was also a statistically significant main effect for judgment type. Contrast 1 was $F(1,46) = 5.50$, $MSE = 813.97$, $p = .023$. Across all queries (within-near/far, between-near/far), JRD judgments had a mean error of 72.0° compared to 62.3° for OBJ judgments.

Figure 16 shows the data for the *f*-location contrasts. The within-room data are on the left side of the figure and the between-room data are on the right side. As shown in the left side of Figure 16**,** mean angular error for within-room queries increased when the facing object (*f*) was in the far location (far-facing *f*) compared to when the facing object was in the near location (near-facing *f*). Mean angular error for near-facing *f* queries was 43.5° compared to 62.5° for far-facing queries. The main effect for within (contrast 3) was $F(1,46) = 30.14$, $MSE = 288.53$, $p < .0001$. Importantly, the near-facing versus far-facing difference was larger for JRD than for OBJ judgments. Contrast 6, the judgment

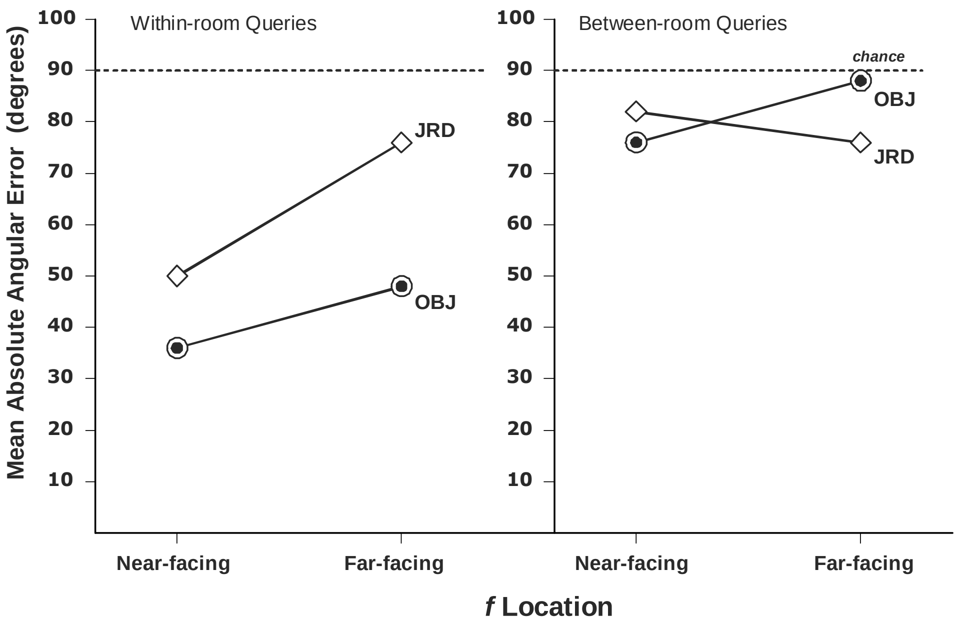


Figure 16. Angular error results for the *f*-location contrasts – full data set.

by within interaction, was statistically significant, $F(1,46) = 5.29$, $MSE = 288.53$, $p = .026$. Mean angular error increased by 27.0° for JRD judgments compared with an error increase of only 11.1° for OBJ judgments.

The data on the right side of Figure 16 are from between-room queries. All of these data were close to the chance level. The chance level is indicated by a dashed line. The main effect for between (contrast 4) was not statistically significant, $F(1,46) = 1.33$, $MSE = 320.90$, $p = .255$. However, there was a marginally significant interaction of judgment by between. Contrast 7 was $F(1,46) = 4.39$, $MSE = 320.90$, $p = .042$. The effect appears to have been produced by a 3.5° decrease in angular error for JRD judgments and an increase of 11.9° in angular error for OBJ judgments.

Matched angles – angular error. Overall, the results for the subset of matched angle data were similar to those obtained for the entire set of data. There was a significant room effect. Contrast 2 was $F(1,46) = 46.41$, $MSE = 809.73$, $p = < .0001$. As

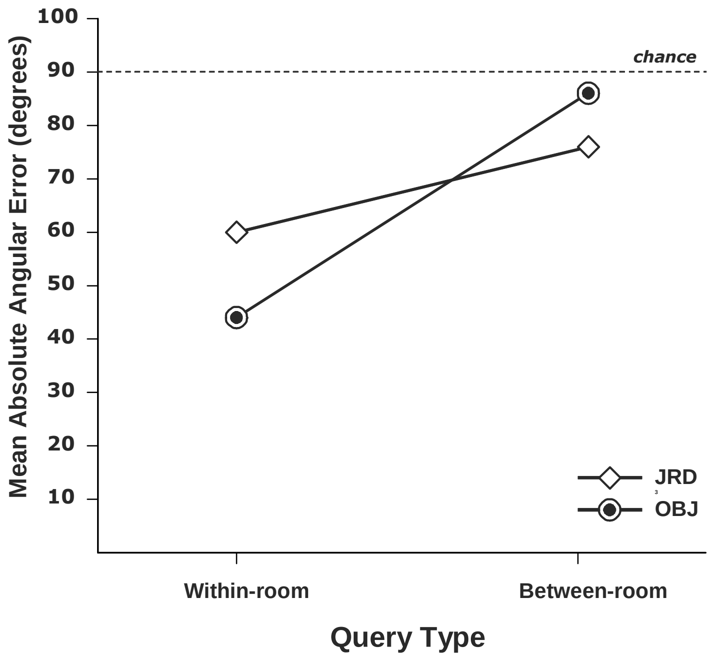


Figure 17. Angular error results for the room effect – matched angles.

Figure 17 shows, mean angular error was greater for between-room than for within-room queries. Mean angular error for within-room queries of was 52.8°, compared to 80.8° for between-room queries. The room effect was larger for OBJ judgments than JRD judgments, as it was for the full set of data. The judgment by room effect interaction (contrast 5) was statistically significant, $F(1,46) = 9.24$, $MSE = 809.73$, $p = .004$. The main effect for judgment type (contrast 1) was not statistically significant, $F(1,46) = .55$, $MSE = 833.01$, $p = .464$. Across all queries (within-near/far, between-near/far), JRD judgments had a mean error of 68.3° compared to 65.3° for OBJ judgments.

Figure 18 shows the data for the *f*-location contrasts. The within-room data are on the left side of the figure and the between-room data are on the right side. As shown in the left side of Figure 18, mean angular error for within-room queries was greater when the facing object (*f*) was in the far location (far-facing *f*) than when the facing object was in the near location (near-facing *f*). The main effect for within (contrast 3) was

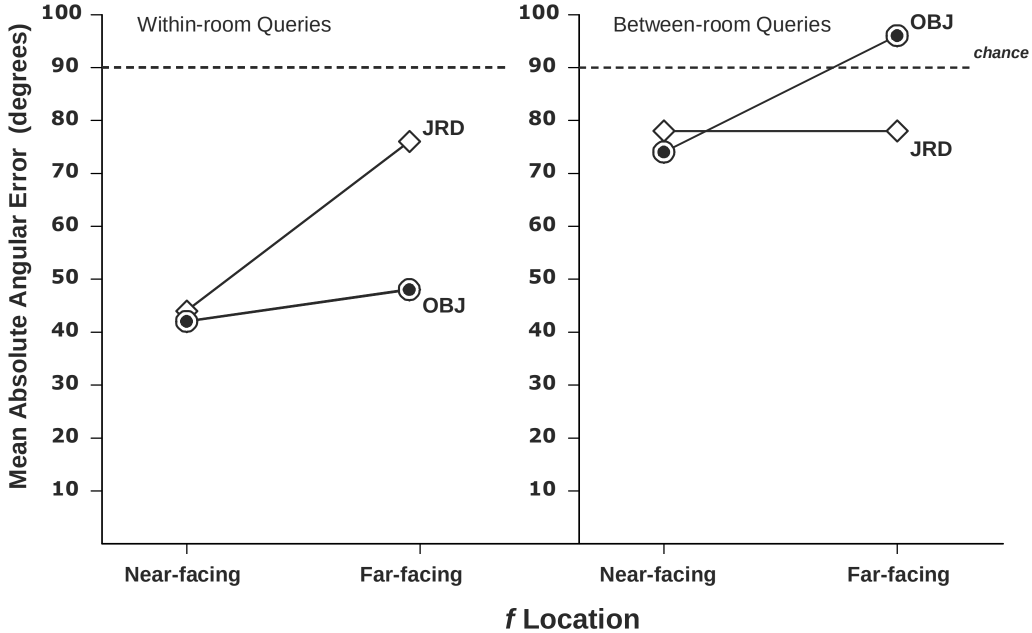


Figure 18. Angular error results for the *f*-location contrasts – matched angles.

statistically significant, $F(1,46) = 15.82$, $MSE = 660.72$, $p = .0002$. Mean angular error for near-facing *f* queries was 43.5° compared to 62.5° for far-facing f queries. Again, this effect was larger for JRD than for OBJ judgments, and the judgment by within interaction (contrast 6) was statistically significant, $F(1,46) = 6.0$, $MSE = 660.72$, $p = .018$. The far-facing minus near-facing mean angular error increase was 27.0° for JRD judgments but was only 16.1° for OBJ judgments.

The data on the right side of Figure 18 are from between-room queries. Note that the means again are near the chance level. The main effect for between (contrast 4) was statistically significant, $F(1,46) = 6.53$, $MSE = 554.81$, $p = .014$. Mean angular error for near-facing *f* queries was 74.7° compared to 87.0° for far-facing *f* queries. The judgment by between interaction (contrast 7) was also significant, $F(1,46) = 7.04$, $MSE = 554.81$, $p = .011$. The mean angular error decreased 0.5° for JRD judgments (from near-facing to far-facing) compared to an increase in error of 25.0° for OBJ judgments. This was a

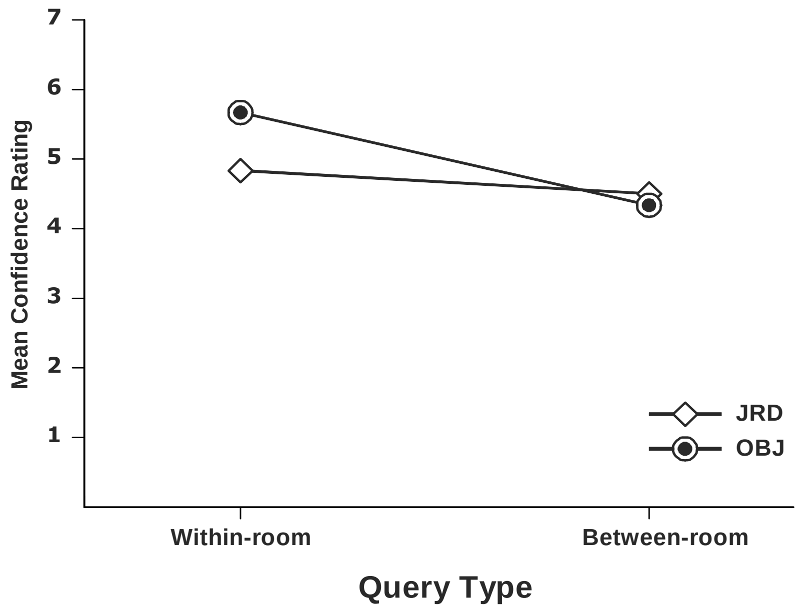


Figure 19. Confidence results for the room effect – full data set.

surprising result in the context of the overall results and it will be addressed in the discussion section.

Confidence. Confidence was measured on a 7-point scale (7 = completely confident their response was correct, 1 = completely unconfident their response was correct), and mean confidence ratings increased when mean absolute angular error decreased. Overall, the results for the confidence data were similar to the angular error data. Contrast 2, the room effect, was statistically significant, $F(1,46) = 91.14$, $MSE = .395$, $p < .0001$. As Figure 19 shows, participants were more confident their responses were correct for within-room queries than for between-room queries. Mean confidence for within-room queries was 4.98 compared to 4.12 for a between-room queries. Figure 19 also shows that the room effect was larger for OBJ judgments than for JRD judgments. The judgment by room effect interaction (contrast 5) was statistically significant, $F(1,46) = 13.61$, $MSE = .395$, $p = .0006$. Participants were more confident

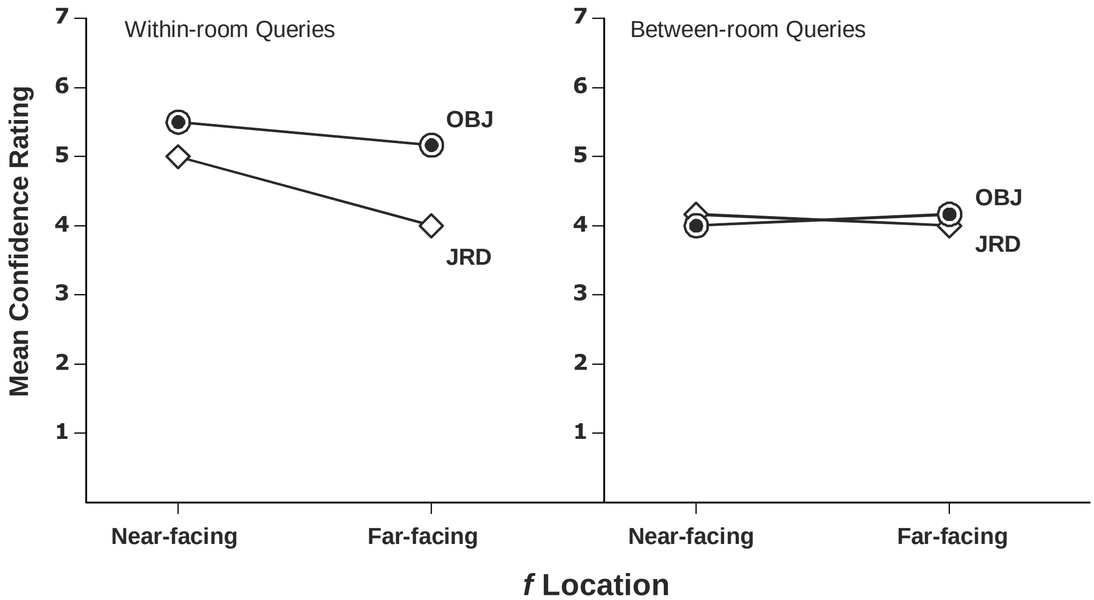


Figure 20. Confidence results for the *f*-location contrasts – full data set.

when answering a within-room OBJ query than when answering a within-room JRD query, having a mean confidence of 5.29 compared to 4.68 for between-room queries. However, OBJ and JRD judgments produced similar results for between-room queries. Unlike the angular error data, the main effect for judgment type (contrast 1) was not statistically significant, $F(1,46) = 1.32$, $MSE = 2.80$, $p = .256$. Across all queries (within-near/far, between-near/far), JRD judgments produced a mean confidence rating of 4.41 compared to 4.69 for OBJ judgments.

Figure 20 shows the data for the *f*-location contrasts. The within-room data are shown on the left side and the between-room data are on the right side of the figure. The left side of the figure shows that confidence decreased for within-room queries when the facing object was in the far location compared to when the facing object was in the near location (near-facing *f*). The main effect for within (contrast 3) was statistically significant, $F(1,46) = 52.42$, $MSE = .205$, $p < .0001$. For within-room queries, mean confidence for a near-facing *f* query was 5.32 compared to 4.65 for a far-facing *f* query. There was also a significant judgment by within interaction, contrast 6 was $F(1,46) = 10.50$, $MSE = .205$, $p = .0022$. The near-facing versus far-facing difference was larger for the JRD judgments compared to OBJ judgments. For within-room queries with a far-facing f location, mean confidence dropped 0.96 for JRD judgments compared to 0.37 for OBJ judgments.

The right side of Figure 20 shows that regardless of whether the between-room query was an OBJ or a JRD judgment, location of the facing object (*f*) made little difference in the confidence of the participants' response. The main effect for between (contrast 4) was not significant, $F(1,46) = .292$, $MSE = .143$, $p = .592$, and the judgment by between interaction (contrast 7) was also not statistically significant, $F(1,46) = 2.63$, $MSE = .143$, $p = .112$.

Matched angles – confidence. For the subset of matched angles only, there was a significant room effect. Contrast 2 was $F(1,46) = 61.32$, $MSE = 0.48$, $p = < .0001$. As Figure 21 shows, mean confidence was greater for within-room queries than for between-

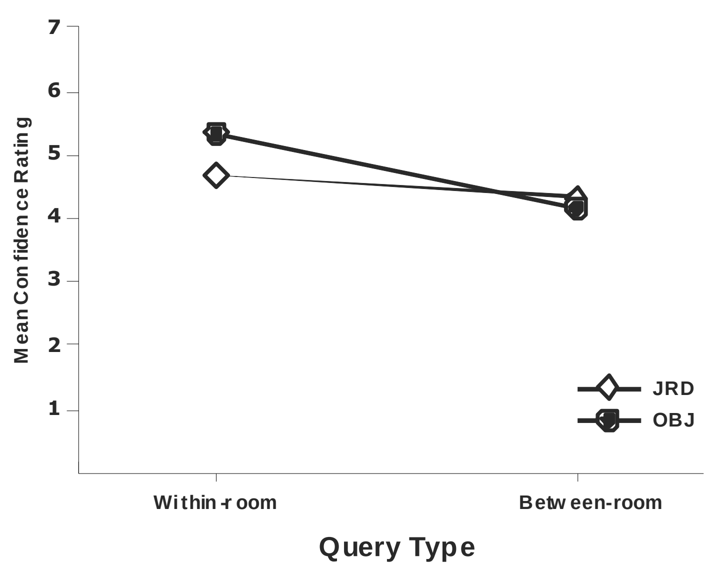


Figure 21. Confidence results for the room effect – matched angles.

room queries. As was found for the full set of data, the room effect was larger for OBJ judgments than JRD judgments. Mean confidence for within-room queries was 4.96 compared to 4.18 for between-room queries. OBJ and JRD judgments produced similar results for between-room queries. The judgment by room effect interaction (contrast 5) was statistically significant, $F(1,46) = 8.95$, $MSE = 0.48$, $p = .004$. The main effect for judgment type (contrast 1) was not statistically significant, $F(1,46) = .788$, $MSE = 3.13$, $p = .256$. Across all queries (within-near/far, between-near/far), JRD judgments had a mean confidence of 4.46 compared to 4.68 for OBJ judgments.

Figure 22 shows the data for the *f*-location contrasts. The within-room data are shown on the left side and the between-room data are on the right side of the figure. The left side of the figure shows that when within-room queries had a far-facing *f*, participants were less confident in their response than when the facing object (*f*) was near-facing. The

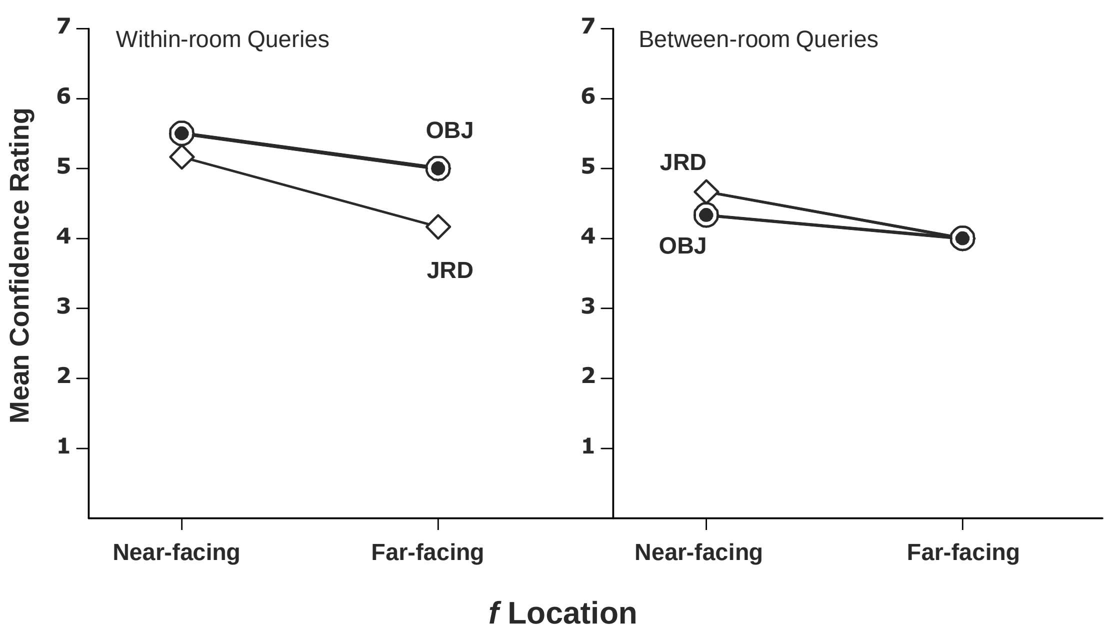


Figure 22. Confidence results for the *f*-location contrasts – matched angles.

main effect for within (contrast 3) was significant, $F(1,46) = 35.25$, $MSE = .327$, $p <$ .0001. Mean confidence for within-room, near-facing *f* queries was 5.31 compared to 4.65 for within-room far-facing *f* queries. The judgment by within interaction (contrast 6) was also significant, $F(1,46) = 8.95$, $MSE = .327$, $p = .005$. The far-facing minus near-facing mean confidence rating for within-room queries dropped 1.04 for JRD judgments compared to only 0.34 for OBJ judgments.

The right side of Figure 22 shows that regardless of whether the between-room query was an OBJ or a JRD judgment, location of the facing object (*f*) made little difference in the confidence of the participants' response. Like the full set of confidence data, the main effect for *f*-between (contrast 4) was not significant, $F(1,46) = .292$, $MSE = .403$, $p = .592$, and the judgment by between interaction (contrast 7) was also not statistically significant, $F(1,46) = .026$, $MSE = .403$, $p = .873$.

Latency. Latency data for the room effect (contrast 2) are shown in Figure 23. Consistent with the angular error and confidence data, there was a significant room

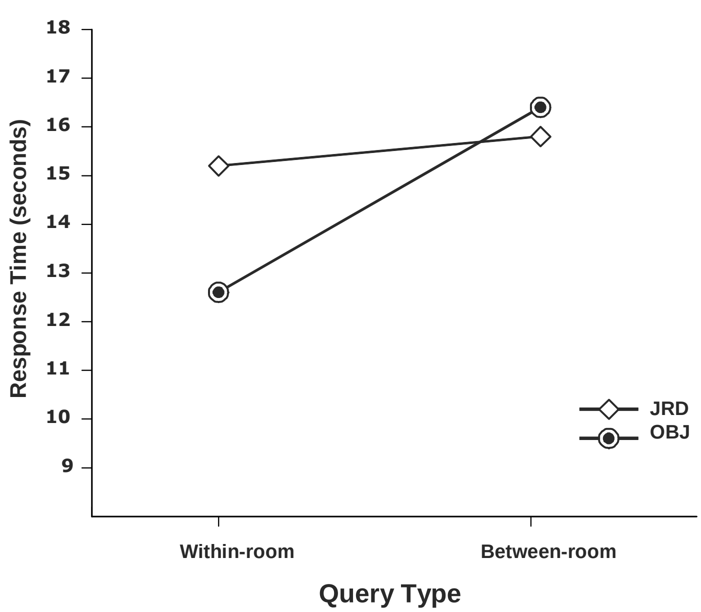


Figure 23. Latency results for the room effect – full data set.

effect, $F(1,46) = 12.38$, $MSE = 17.166$, $p = .001$. As Figure 23 shows, latency was longer for between-room than for within-room queries. Mean latency for within-room queries of was 14.0 s compared to 16.1 s for between-room queries. Figure 23 also shows that the room effect was larger for OBJ than for JRD judgments. The judgment by room effect interaction (contrast 5) was statistically significant, $F(1,46) = 8.05$, $MSE = 17.166$, $p = .001$. OBJ queries had a shorter mean latency than JRD queries when queries were within-room, resulting in a mean latency of 14.68 s compared to 15.42 s for the JRD judgments. OBJ and JRD judgments produced similar results for between-room queries. There was no significant main effect for judgment type (contrast 1), $F(1,46) = .249$, $MSE = 106.771$, $p = .622$. Across all queries (within-near/far, between-near/far), JRD judgments had a mean latency of 15.4 s compared to 14.7 s for OBJ judgments.

Figure 24 shows the data for the *f*-location contrasts. The within-room data are shown on the left side and the between-room data are on the right side of the figure. The

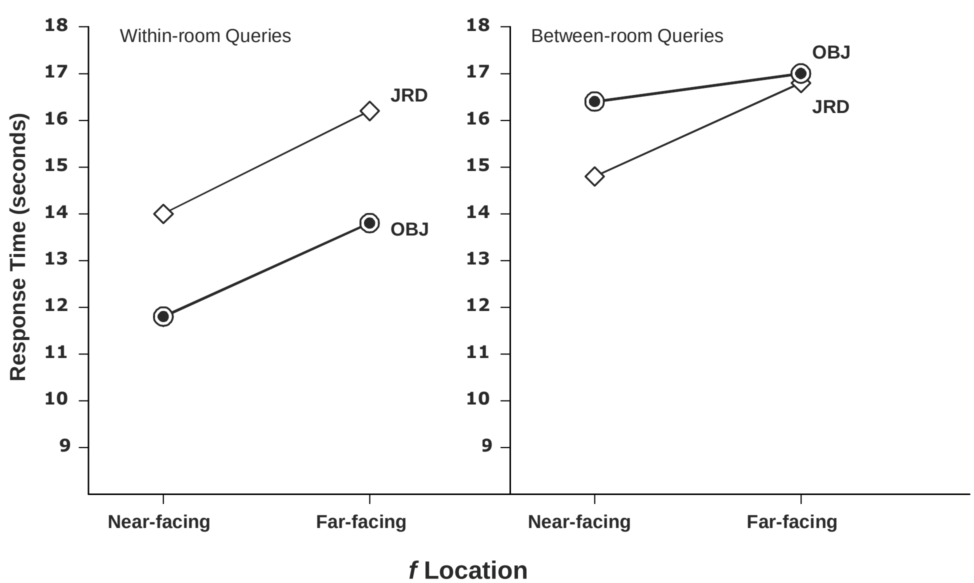


Figure 24. Latency results for the *f*-location contrasts – full data set.

main effect for within (contrast 3) was statistically significant, $F(1,46) = 6.33$, $MSE = 14.399$, $p = .0154$. The left side of Figure 24 shows that when within-room queries had a far-facing *f*, mean latency increased compared to queries that had a near-facing *f*. Mean latency for near-facing *f* queries was 13.02 s compared to 14.97 s for far-facing *f* queries. Unlike the angular error and confidence data, the judgment by within interaction (contrast 6) was not statistically significant, $F(1,46) = .030$, $MSE =14.399$, $p = .863$. The far-facing minus near-facing mean latency increased 2.08 s for JRD The far-The far-facing judgments minus near-facing mean latency increased 2.08 s for JRD judgments compared to 1.82 s for OBJ judgments.

The right side of Figure 24 shows the latency data for between-room queries. The main effect for between (contrast 4) was marginally significant, $F(1,46) = 4.82$, $MSE = 7.867$, $p = .033$. Between-room queries with a near-facing *f* had a mean latency of 15.47 s compared to 16.73 s queries with a far-facing *f*. The interaction of judgment by between (contrast 7) was not statistically significant, $F(1,46) = 2.24$, $MSE = 7.867$, $p = .141$.

Matched angles – latency. For the subset of matched angles only, latency data for the room effect are shown in Figure 25. Consistent with the full data set for latency, the room effect (contrast 2) was statistically significant, $F(1,46) = 12.05$, $MSE = 17.657$, $p = .0011$. As Figure 25 shows, latency was greater for between-room than for within-room queries. Mean latency for within-room queries of was 13.5 s compared to 15.6 s for between-room queries. Figure 25 also shows that the room effect was larger for OBJ than for JRD judgments. The judgment by room effect interaction (contrast 5) was statistically significant, $F(1,46) = 7.79$, $MSE = 17.657$, $p = .0076$. JRD judgments were

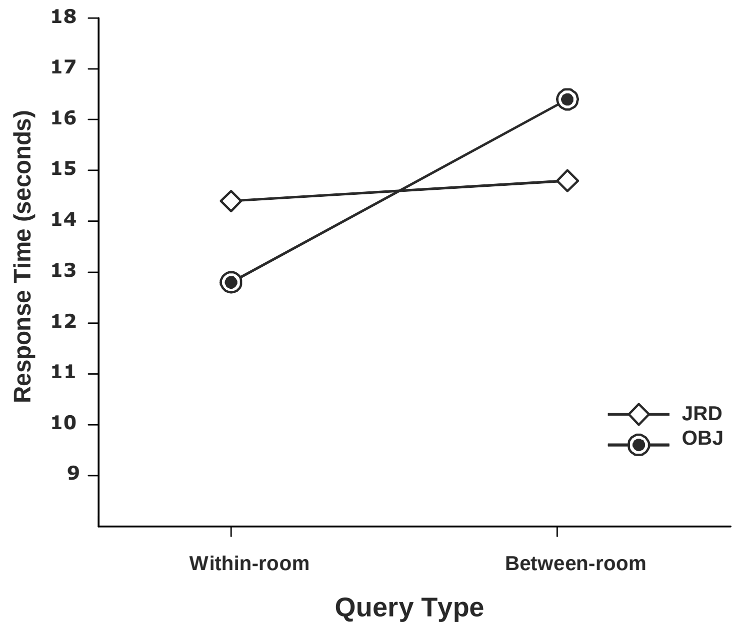


Figure 25. Latency results for the room effect – matched angles.

not sensitive to the within-room versus between-room difference, which was 0.4 s. However, OBJ judgments had shorter response times for within-room queries than between-room queries, increasing by 3.8 s. Unlike the overall set of data, the between-room queries for JRD and OBJ judgments do not appear to be comparable. However, a comparison of these two data points alone depends on between-subjects variability. Implications will be discussed in the discussion. There was no significant main effect for judgment type. Contrast 1 was $F(1,46) = .0009$, $MSE = 106.502$, $p = .976$. Across all queries (within-near/far, between-near/far), both JRD and OBJ judgments had a mean latency of 14.6 s.

Figure 26 shows the matched angle data for the *f*-location contrasts. The within-room data are shown on the left side and the between-room data are on the right side of the figure. The main effect for within (contrast 3) was significant, $F(1,46) = 16.33$, $MSE = 14.818$, $p = .0002$. The left side of Figure 26 shows that when within-room queries

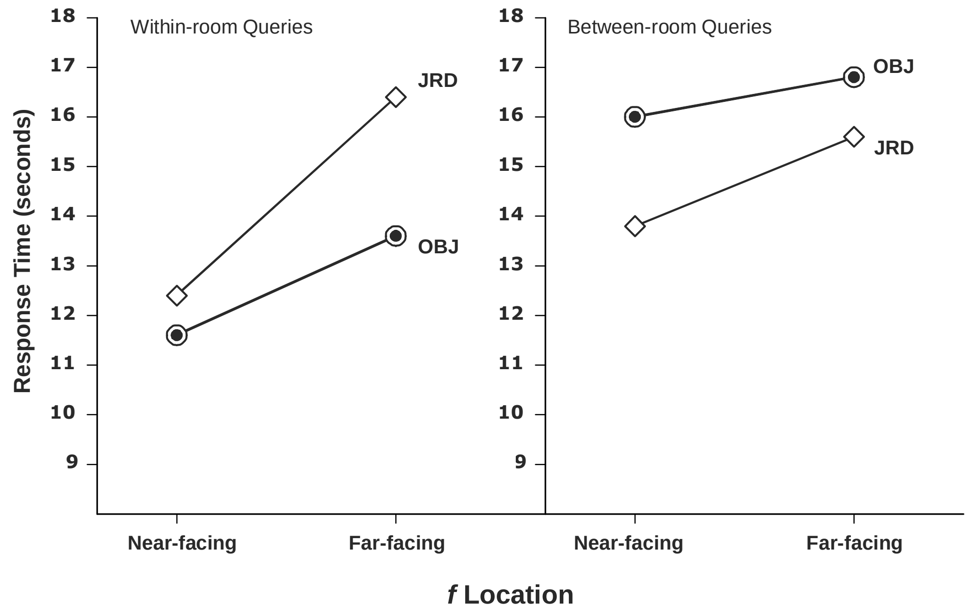


Figure 26. Latency results for the *f*-location contrasts – matched angles.

had a far-facing *f*, mean latency increased compared to queries that had a near-facing *f*. Mean latency for near-facing *f* queries was 12.0 s compared to 15.1 s for far-facing *f* queries. Like the full data set, the judgment by within interaction (contrast 6) was not statistically significant, $F(1,46) = 1.97$, $MSE = 14.818$, $p = .166$.

The right side of Figure 26 shows the latency data for between-room queries. Unlike the full data set, the main effect for between (contrast 4) was not statistically significant, $F(1,46) = 3.40$, $MSE = 13.845$, $p = .072$. The judgment by between interaction (contrast 7) was also not significant, $F(1,46) = .449$, $MSE = 13.845$, $p = .506$.

Map Data

As described in the introduction, both JRD and OBJ query scores could be obtained from each individual map, regardless of the pointing judgment task that a participant used. Maps were used to answer the same queries that were answered in the pointing tasks. The map data were analyzed in three ways, parallel scoring, JRD scoring, and OBJ scoring. In the parallel scoring analysis, the JRD judgment group and their corresponding JRD map scores were compared to the OBJ judgment group and their OBJ map scores. In the JRD scoring analysis, maps for both judgment groups were compared, only looking at their JRD query scores. In the OBJ scoring analysis, maps for both judgment types were compared, only looking at their OBJ query scores. The map data were analyzed with the same seven orthogonal contrasts used to analyze the pointing data. The map data was analyzed using both the entire data set and the subset of data with matched angles. A 5% level of confidence was used for all statistical decisions.

Parallel scoring. The data from the parallel map scoring analysis are shown in Figure 27. The room effect (contrast 2) was statistically significant, $F(1,46) = 63.26$, $MSE = 265.95$, $p < .0001$. Mean angular error was greater for between-room than for

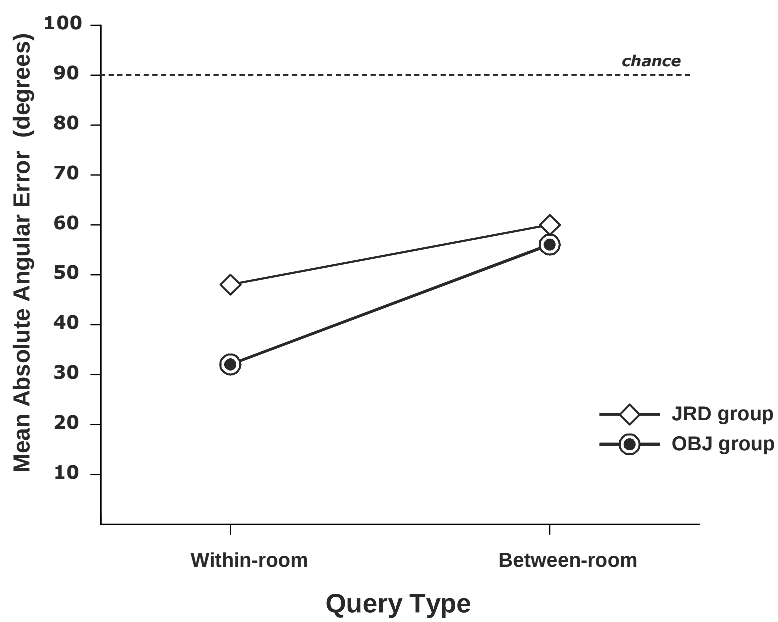


Figure 27. Parallel map scoring for the room effect – full data set.

within-room queries. Mean angular error for within-room scores was 40.6° compared to 59.3° for between-room queries. The judgment by room effect interaction (contrast 5) was also significant, $F(1,46) = 7.80$, $MSE = 265.95$, $p = .008$. Similar to the pointing data, the room effect was larger for the OBJ judgment group with OBJ scoring compared to the JRD judgment group with JRD scoring. OBJ judgments produced less angular error when the query was within-room, having a mean angular error or 32.6° compared to 48.6° for JRD judgments. OBJ and JRD judgments produced similar results for between-room queries. There was a marginally significant main effect of judgment type. Contrast 1 was $F(1,46) = 4.76$, $MSE = 902.75$, $p = .034$. Overall, the OBJ judgments with OBJ scores produced a mean angular error of 45.2° compared to 54.7° for JRD judgments with JRD scores.

Figure 28 shows the data for the *f*-location contrasts. The within-room data are on the left side and the between-room data are on the right side of the figure. The main effect

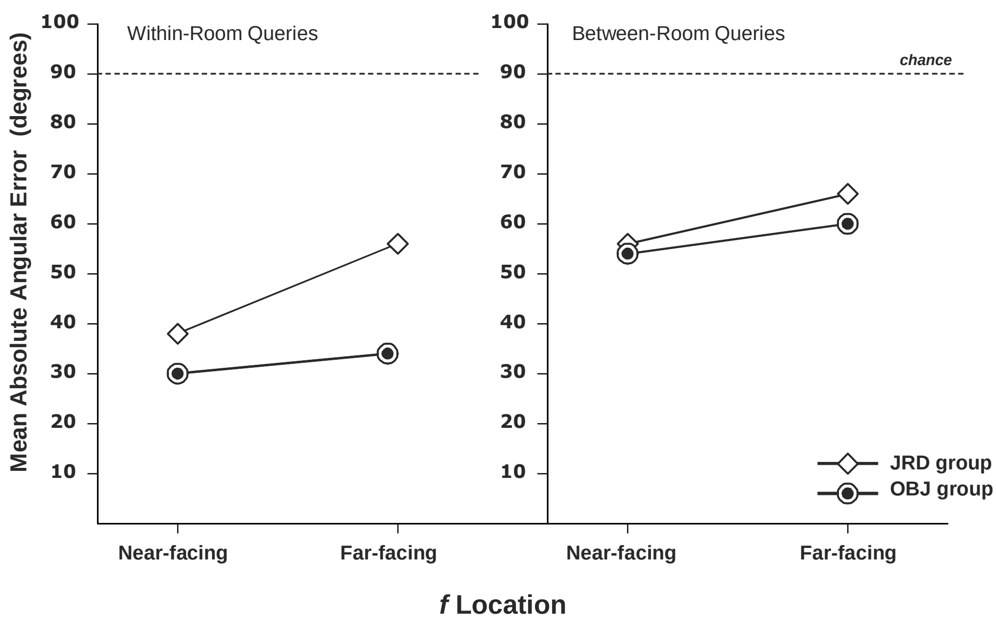


Figure 28. Parallel map scoring for the *f*-location contrasts – full data set.

for within (contrast 3) was statistically significant, $F(1,46) = 12.40$, $MSE = 269.22$, $p = .001$. As shown in the left side of Figure 28, within-room mean angular error increased for a far-facing *f* compared to within-room scores with a near-facing *f*. Mean angular error for near-facing *f* scores was 34.7° compared to 46.5° for within-room far-facing *f* scores. The effect was nominally larger for JRD than for OBJ judgments, but the judgment by within interaction (contrast 6) was not statistically significant, $F(1,46) = 3.91$, $MSE = 269.22$, $p = .054$.

The data on the right side of Figure 28 show the between-room scores. The main effect for between (contrast 4) was not statistically significant, $F(1,46) = 3.64$, $MSE = 279.48$, $p = .063$. The interaction of judgment by between (contrast 7) also was not significant, $F(1,46) = .115$, $MSE = 279.48$, $p = .736$.

Matched angles - parallel scoring. The data from the parallel map scoring analysis are shown in Figure 29. Like the full data set, the room effect (contrast 2) was statistically significant, $F(1,46) = 29.55$, $MSE = 492.51$, $p < .0001$. Mean angular error

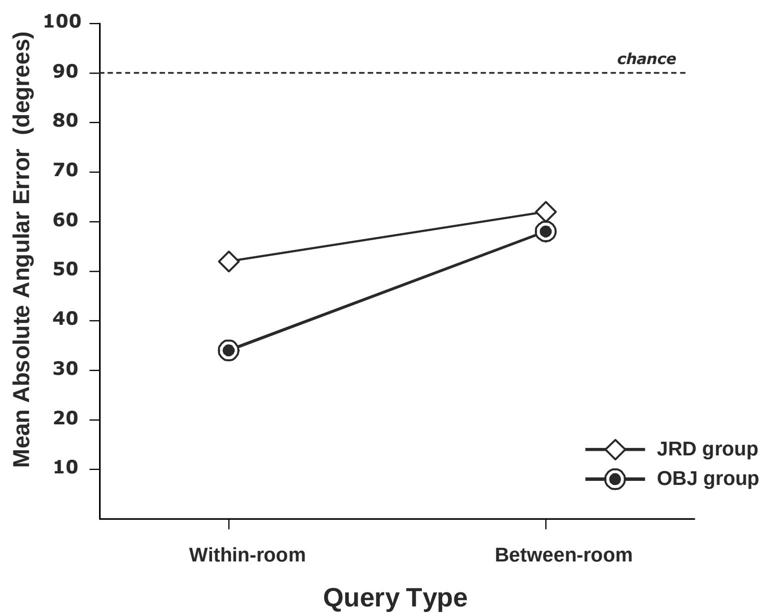


Figure 29. Parallel map scoring for the room effect – matched angles.

was greater for between-room than for within-room scores. Mean angular error for within-room scores was 42.6° compared to 60.1° for between-room scores. The judgment by room effect interaction (contrast 5) was statistically significant, $F(1,46) = 6.22$, $MSE = 492.51$, $p = .0163$. However, overall absolute angular error was less for OBJ judgments than for JRD judgments. The main effect of judgment (contrast 1) also was statistically significant , $F(1,46) = 6.37$, $MSE = 1023.39$, $p = .0151$. In particular, the OBJ judgments with OBJ scores produced a mean angular error of 45.5° compared to 56.7° for JRD judgments with JRD scores.

Figure 30 shows the data for the *f*-location contrasts. The within-room data are on the left side and the between-room data are on the right side of the figure. As shown in the left side of Figure 30**,** the main effect for within (contrast 3) was statistically

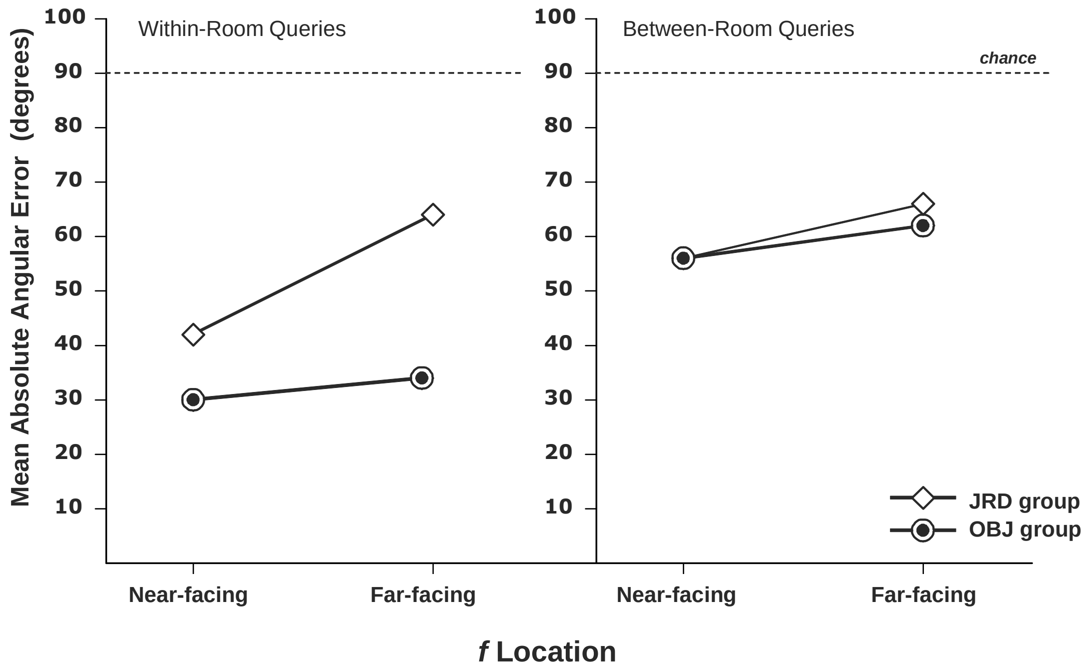


Figure 30. Parallel map scoring for the *f*-location contrasts – matched angles.

significant, $F(1,46) = 7.53$, $MSE = 583.02$, $p = .0086$. Within-room mean angular error increased for a far-facing *f* compared to a near-facing *f*. Mean angular error for near-facing *f* scores was 35.9° compared to 49.4° for far-facing *f* scores. However, the judgment by within interaction (contrast 6) was not statistically significant, $F(1,46) = 2.60$, $MSE = 583.02$, $p = .1134$.

The data on the right side of Figure 30 show the between-room scores. The main effect for between (contrast 4) was not statistically significant, $F(1,46) = 1.43$, $MSE = 792.26$, $p = .2376$. The interaction of judgment by between (contrast 7) was also not significant, $F(1,46) = .086$, $MSE = 792.26$, $p = .7703$.

JRD scoring. Regardless of the judgment type participants used during the pointing task (JRD, OBJ), JRD query scores could be calculated from each individual map. The data from the JRD scoring analysis are shown in Figures 31 and 32. As Figure 31 shows, when the maps from both judgment groups (JRD and OBJ) were analyzed

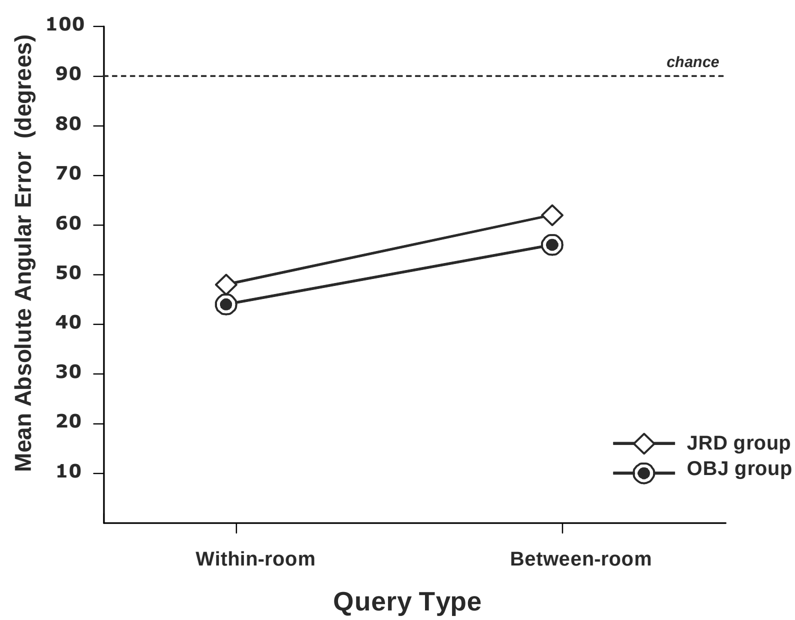


Figure 31. JRD map scoring for the room effect – full data set..

using only the JRD query scores, the room effect (contrast 2) was statistically significant, $F(1,46) = 26.50$, $MSE = 243.0$, $p < .0001$. Mean angular error was greater for between-room than for within-room scores. Mean angular error for within-room scores was 46.7° compared to 58.3° for between-room scores. However, both judgment groups showed similar angular error. The judgment by room effect interaction (contrast 5) was not statistically significant, $F(1,46) = .063$, $MSE = 243.0$, $p = .804$. The main effect of judgment type (contrast 1) was not statistically significant, $F(1,46) = .870$, $MSE = 1103.2$, $p = .356$. Across all queries (within-near/far, between-near/far), the JRD group had a mean JRD query angular error of 54.7° compared to 50.3° for the OBJ group.

Figure 32 shows the data for the *f*-location contrasts. The within-room data are on the left side and the between-room data are on the right side of the figure. The left side of Figure 32 shows that mean angular error was greater for queries with a far-facing *f*-location compared to queries with a near-facing *f*-location. The main effect for within

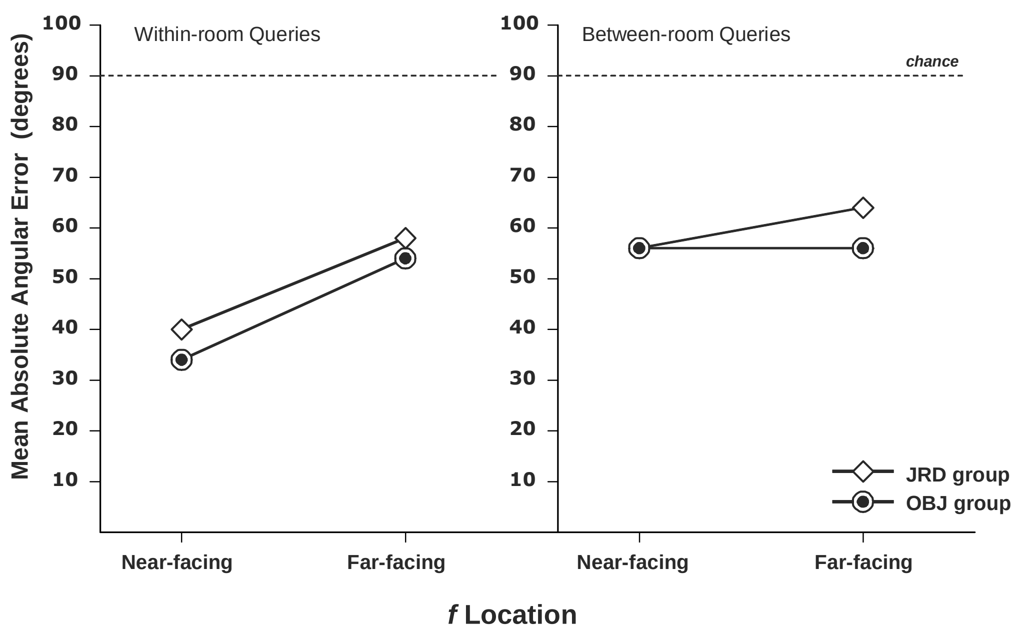


Figure 32. JRD map scoring for the *f*-location contrasts – full data set.

(contrast 3) was statistically significant, $F(1,46) = 23.83$, $MSE = 384.77$, $p < .0001$. Mean angular error for within-room, near-facing *f* scores was 36.9° compared to 54.5° for within-room, far-facing *f* scores. However, these differences did not depend on the judgment type group. The judgment by within interaction (contrast 6) was not statistically significant, $F(1,46) = .080$, $MSE = 384.77$, $p = .780$.

The data on the right side of Figure 32 show the between-room scores. No differences were found. The main effect for between (contrast 4) was not statistically significant, $F(1,46) = .533$, $MSE = 322.06$, $p = .469$. The interaction of judgment by between (contrast 7) was also not significant, $F(1,46) = 1.86$, $MSE = 322.06$, $p = .180$.

Matched angles - JRD scoring. The data from the JRD scoring analysis are shown in Figures 33 and 34. As Figure 33 shows, when both judgment group maps (JRD and OBJ) were analyzed with only the JRD map scores, the room effect (contrast 2) was statistically significant, $F(1,46) = 20.66$, $MSE = 312.10$, $p < .0001$. Mean angular error

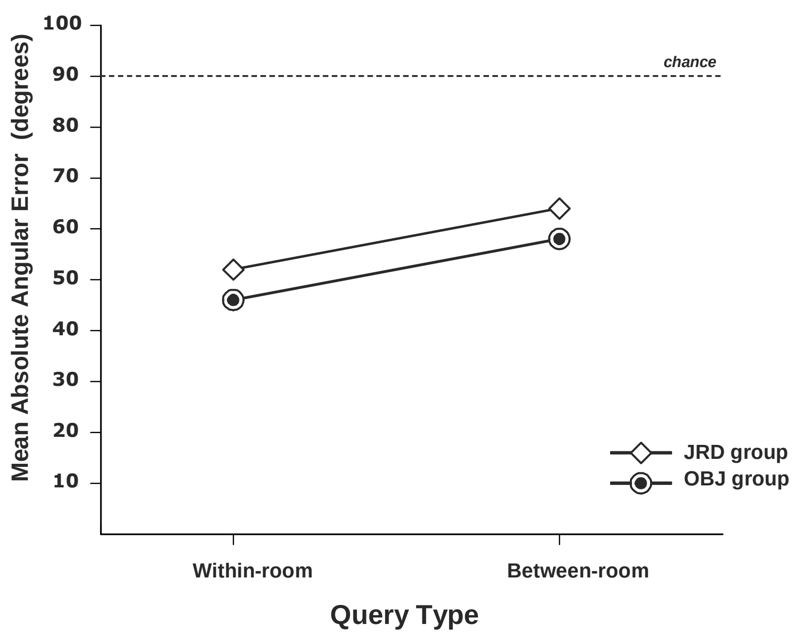


Figure 33. JRD map scoring for the room effect – matched angles.

was greater for between-room than for within-room scores. Mean angular error for within-room scores was 48.5° compared to 60.1° for between-room scores. However, both judgment groups showed similar errors in the JRD map scores, and the judgment by room effect interaction (contrast 5) was not statistically significant, $F(1,46) = .720$, $MSE = 312.10$, $p = .401$. The main effect of judgment type (contrast 1) was not statistically significant, $F(1,46) = 1.07$, $MSE = 1473.18$, $p = .306$. Across all queries (within-near/far, between-near/far), the JRD group had a mean JRD query angular error of 57.2° compared to 51.4° for the OBJ group.

Figure 34 shows the data for the *f*-location contrasts. The within-room data are on the left side and the between-room data are on the right side of the figure. The left side of Figure 34 shows that mean angular error was greater for queries with a far-facing *f*-location compared to queries with a near-facing *f*-location. The main effect for within

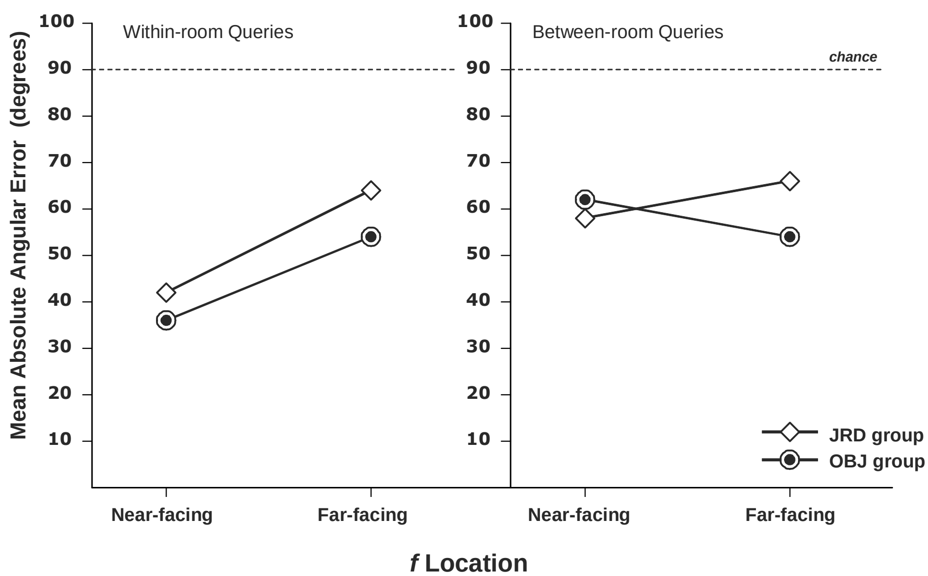


Figure 34. JRD map scoring for the *f*-location contrasts – matched angles.

(contrast 3) was statistically significant, $F(1,46) = 15.24$, $MSE = 600.53$, $p = .0003$. Mean angular error for within-room, near-facing *f* scores was 38.7° compared to 58.3° for within-room, far-facing *f* scores. The judgment by within interaction (contrast 6) was not statistically significant, $F(1,46) = .152$, $MSE = 600.53$, $p = .698$.

The data on the right side of Figure 34 show the between-room scores. No differences were found. The main effect for between (contrast 4) was not statistically significant, $F(1,46) = .004$, $MSE = 884.62$, $p = .948$. The interaction of judgment by between (contrast 7) was also not significant, $F(1,46) = 2.18$, $MSE = 844.62$, $p = .147$.

OBJ scoring. Regardless of the judgment type used by participants during the pointing task (JRD, OBJ), OBJ query scores could be calculated from each individual map. The data from the OBJ scoring analysis are shown in Figure 35 and 36. The room effect (contrast 2) was statistically significant, $F(1,46) = 57.1$, $MSE = 399.84$, $p < .0001$. As shown in Figure 35, mean angular error was greater for between-room than for

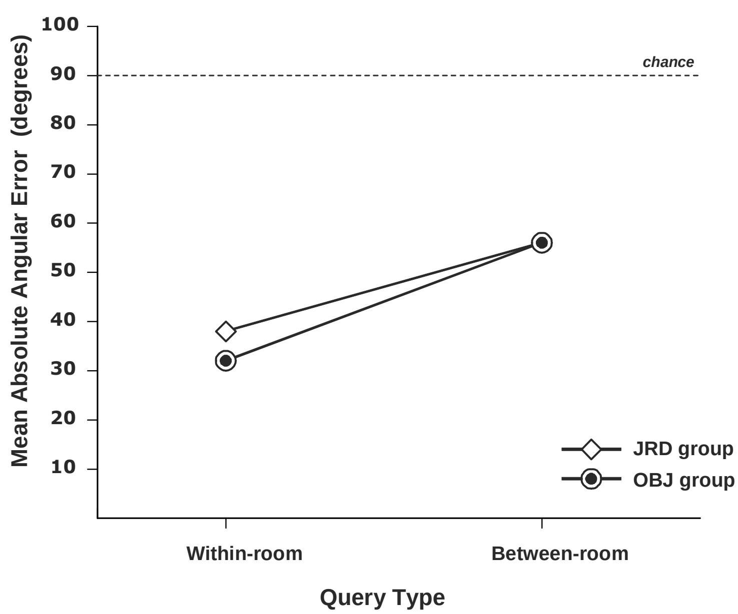


Figure 35. OBJ map scoring for the room effect – full data set.

within-room scores. Mean angular error for within-room scores was 36.0° compared to 57.8° for between-room scores. Importantly, the judgment by room effect interaction (contrast 5) was not statistically significant, $F(1,46) = 1.46$, $MSE = 399.84$, $p = .2337$. The main effect of judgment type (contrast 1) also was not statistically significant, $F(1,46) = .612$, $MSE = 867.54$, $p = .4379$. Across all queries (within-near/far, between-near/far), the JRD group had a mean angular error of 48.6° compared to 45.2° for the OBJ group.

Figure 36 shows the data for the *f*-location contrasts. The within-room data are on the left side and the between-room data are on the right side of the figure. As shown in the left side of Figure 36**,** when the facing object (*f*) was far-facing**,** mean angular error increased compared to scores when the facing object (*f*) was near-facing. Mean angular error for the within-room, near-facing *f* scores was 32.4° compared to 39.6° for within-room, far-facing *f* scores. The main effect for within (contrast 3) was statistically

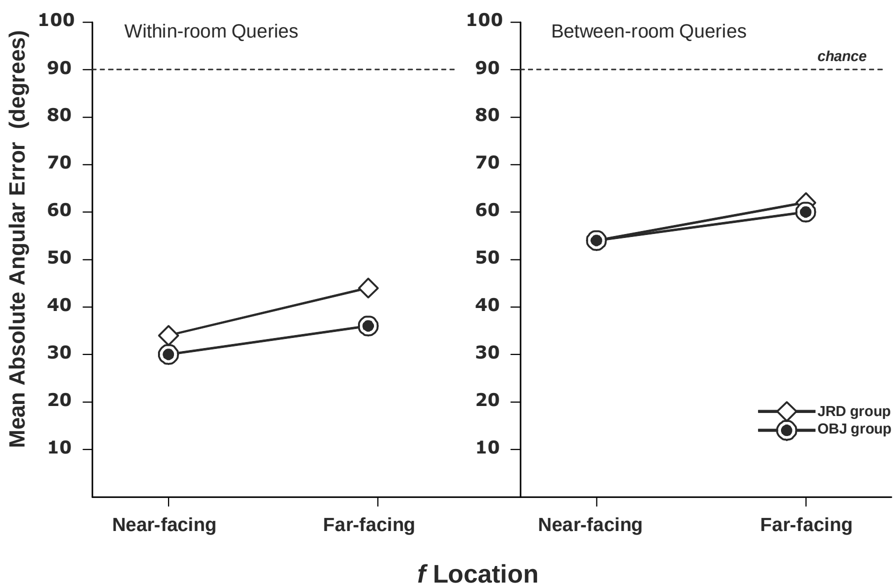


Figure 36. OBJ map scoring for the *f*-location contrasts – full data set.

significant, $F(1,46) = 5.62$, $MSE = 220.96$, $p = .022$. The judgment by within interaction (contrast 6) was not statistically significant, $F(1,46) = .444$, $MSE = 220.96$, $p = .5082$.

The data on the right side of Figure 36 show the between-room OBJ map scores. Unlike the JRD scores, the main effect for between (contrast 4) was marginally significant, $F(1,46) = 5.145$, $MSE = 170.42$, $p = .028$. Between-room queries with a near-facing *f* had a mean angular error of 54.8° compared to 60.8° for queries with a far-facing *f*. The interaction of judgment by between (contrast 7) was not significant, $F(1,46) = .0678$, $MSE = 170.42$, $p = .7961$.

Matched angles - OBJ scoring. The data from the OBJ scoring analysis are shown in Figure 37 and 38. The room effect (contrast 2) was statistically significant, $F(1,46) = 35.07$, $MSE = 670.23$, $p < .0001$. Mean angular error was greater for between-room than for within-room scores. As shown in Figure 37 match, mean angular error for

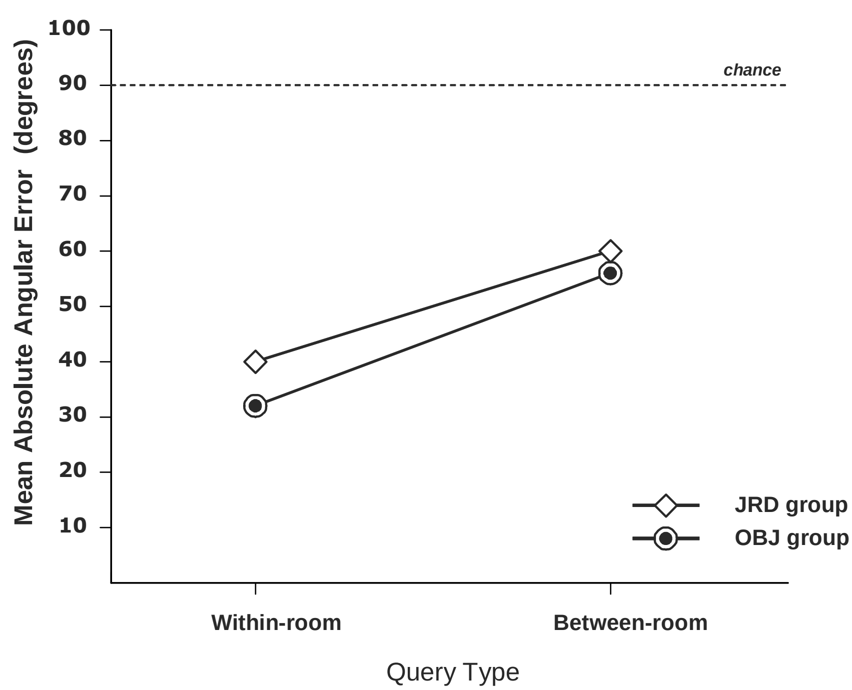


Figure 37. OBJ map scoring for the room effect – matched angles.

within-room scores was 36.6° compared to 58.7° for between-room scores. However, the judgment by room effect interaction (contrast 5) was not statistically significant, $F(1,46) = .766$, $MSE = 670.23$, $p = .386$. The main effect of judgment type (contrast 1) was not statistically significant, $F(1,46) = .762$, $MSE = 1131.83$, $p = .3872$. Across all queries (within-near/far, between-near/far), the JRD group had a mean OBJ query angular error of 49.7° compared to 45.5° for the OBJ group.

Figure 38 shows the data for the *f*-location contrasts. The within-room data are on the left side and the between-room data are on the right side of the figure. As shown in the left side of Figure 38, when the facing object (*f*) was far-facing**,** mean angular error did not increase compared to scores when the facing object (*f*) was near-facing. Unlike the full data set, the main effect for within (contrast 3) was not statistically significant, $F(1,46) = .265$, $MSE = 546.97$, $p = .609$. However, the judgment by within interaction (contrast 6) was also not statistically significant, $F(1,46) = .426$, $MSE = 546.97$, $p = .5174$.

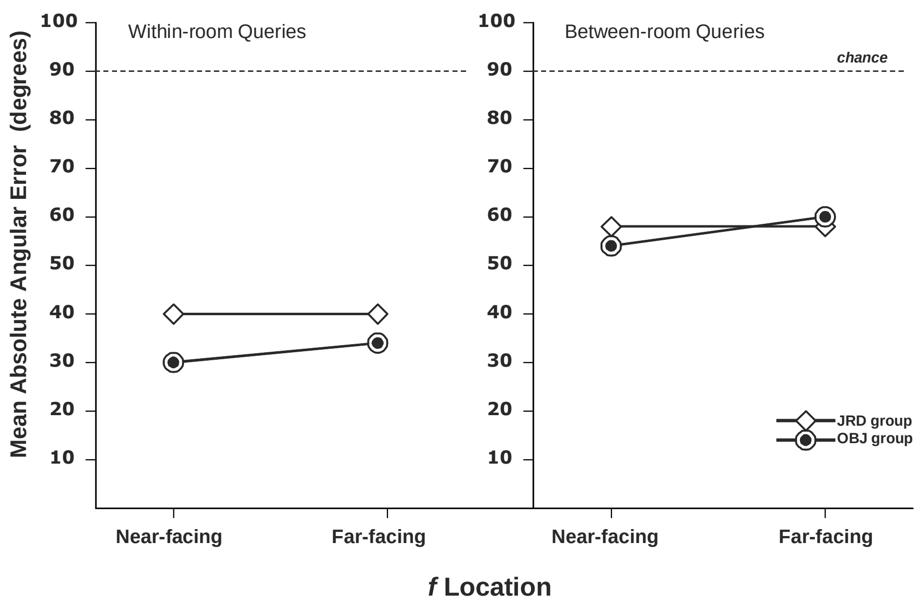


Figure 38. OBJ map scoring for the *f*-location contrasts – matched angles.

The data on the right side of Figure 38 show the between-room OBJ map scores. The main effect for between (contrast 4) was not statistically significant, $F(1,46) = .411$, $MSE = 475.40$, $p = .5245$. The interaction of judgment by between (contrast 7) was also not significant, $F(1,46) = .275$, $MSE = 475.40$, $p = .6026$.

Map data summary. The results of the sketch maps data showed that the differences found for pointing accuracy were replicated when the JRD judgment group's sketch maps were scored using JRD scoring and the OBJ judgment group's sketch maps were scored using OBJ scoring (parallel scoring). Thus, the two measures converged. Importantly, differences between the two judgment types were not found when all sketch maps were scored with JRD queries or all sketch maps were scored with OBJ queries. In these cases there were no main effects of judgment group and no interactions with judgment group. Overall OBJ scoring led to better accuracy than JRD scoring, as shown in the parallel scoring analysis.

IV. DISCUSSION

A major goal of this study was to evaluate OBJ and JRD judgments as measures of configural spatial knowledge acquisition. The two judgments were shown to reflect two different models of spatial representations in memory. The predictions assume that judgments that are more consistent with a mental representation are made more accurately and more easily. Thus, better performance should be reflected in reduced angular error, increased confidence about a pointing response, and shorter latency.

The two models of spatial representation that were identified were the quasi-Euclidean model and the object reference model. If the quasi-Euclidean model is a better description of configural spatial memory representations, then JRD judgments are more natural than OBJ judgments and they should have greater accuracy, more confidence and shorter latency. The object reference model makes the opposite predictions. OBJ judgments should be better than JRD judgments.

Main Conclusions

Overall, the object reference model was more consistent with the results than the quasi-Euclidean model. Performance with OBJ judgments was more likely to have less angular error than performance with JRD judgments. These results showed up most clearly when the room effect was examined. In all cases, the room effect was larger for

OBJ than for JRD judgments. Absolute angular error was lower for OBJ than for JRD for within-room queries. There tended to be little or no difference for between-room queries. Similar results were found in the analyses of the confidence and latency data.

Judgment Type. Both measurement model predictions are based on assumptions about memory representations and storage characteristics of memory. A single type of measure could reflect either storage or retrieval differences. The data suggested that the differences were memory storage differences because two different retrieval methods lead to converging findings. Besides studying pointing judgments, participants' sketch maps of the environment also were examined. The sketch maps results were also consistent with the hypothesis that the object reference model is more reflective of how people represent space in memory. Sketch maps depended only on how they were scored, either using JRD or OBJ queries. No differences were found when both judgment type groups had their sketch maps scored in the same way (all maps JRD or all maps OBJ). However, when parallel scoring was used, the findings were similar to those found for pointing accuracy – OBJ scoring resulted in reduced angular error compared to JRD scoring.

Room Effect. The differences between OBJ and JRD judgments showed up most clearly for within-room conditions. Few differences were found for between-room conditions. Between-room pointing accuracy was close to chance, making accuracy differences difficult to detect. However, between-room judgment differences were not consistently found for confidence ratings or for latency measures, which were not near a data ceiling. Thus, the superiority of OBJ judgments is only clear for within-room judgments. Nevertheless, JRD judgments were not consistently found to be superior to OBJ judgments for any conditions.

The Location of f. The facing object (*f*) was the middle component of the JRD judgment. I am not aware of any research that has addressed the impact of the location of facing objects on the accuracy of angular error for JRD judgments. Therefore, the location of the facing object (*f*) was systematically manipulated in this study, providing an opportunity to determine if location influenced JRD performance. Our analyses found some evidence that JRD accuracy suffered on within-room queries when facing object locations were in different rooms from the standing at (*s*) and target locations (*t*). Between-room queries were close to ceiling and the location of the facing object (*f*) did not reliably increase angular error.

For comparison purposes in this study, OBJ queries were yoked to JRD questions. Queries were yoked by using identical standing at (*s*) and target locations (*t*) for each JRD and OBJ query. Each participant in the study received a total of 32 queries. For example, query 4 used the same standing at (*s*) and target (*t*) objects regardless of whether the participant was in the JRD or OBJ group. The same rule applied to all 32 queries. Facing location (*f*) also was manipulated in order to investigate JRD judgments. Because the OBJ judgment does not have a middle component, the facing object (*f*) category (near, far) was merely a matching operation, creating OBJ queries that matched JRD queries in their (*s*) and (*t*) locations for each of the 32 queries. As such, OBJ judgments should have been insensitive to facing object (*f*) locations because the facing object was, in reality, a non-existent or irrelevant variable in the OBJ query.

The analyses of the facing object (*f*) location revealed some unexpected results for OBJ judgments, but only in the pointing data. In particular, the angular error for OBJ queries was found to change depending on the location of the facing object in the JRD queries. Figure 39 is a duplicate of Figure 16 with the addition of arrows showing the unexpected OBJ angular error increases. These data show that for both within-room and between-room OBJ queries, pointing angular error increased when the (JRD) facing object (*f*) was in a far location compared to a near location. A similar pattern of results occurred in the matched angle data (see Figure 18). Post-hoc Tukey tests were performed on OBJ judgments for both data sets (full, matched angle) in order to compare the two within-room means (near-facing, far-facing) as well as the two between-room means (near-facing, far-facing). Both interactions in the full data set and the matched angle set (within-room queries, between-room queries) x location of the facing object (*f*) were

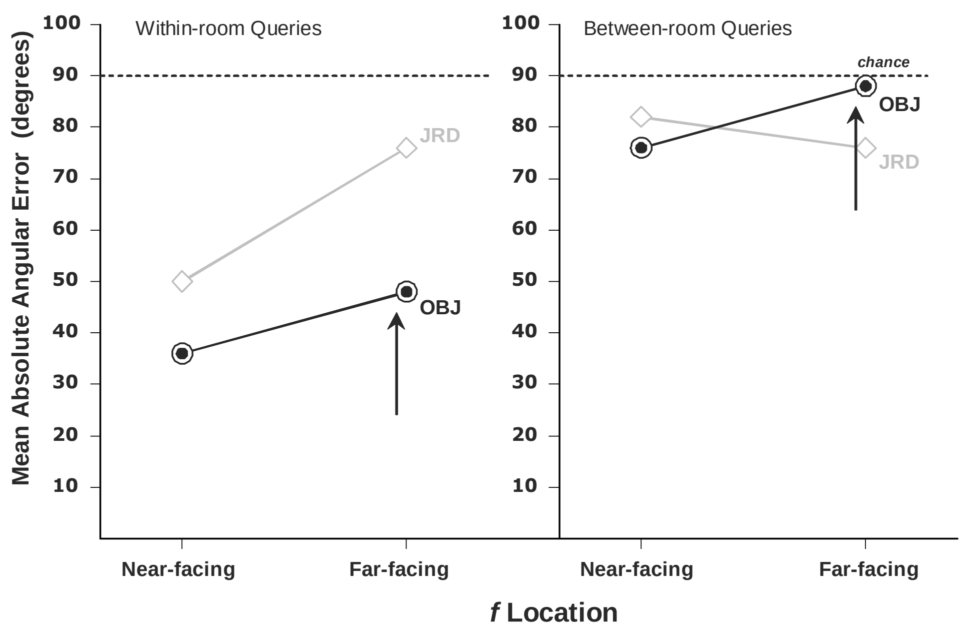


Figure 39. The near to far problem. Angular error for OBJ judgments increased significantly when the facing object (*f*) changed from nearing-facing to far-facing.

statistically significant in the original analyses. The Tukey tests used the MS error from the original interaction. In each Tukey test, these two OBJ means (within-near and within-far) were assumed to be the only two of interest. Level of significance was 0.05. Shown in the left graph in Figure 39, the near-facing to far-facing increase of 11.1° (36.1° to 47.2°) for within-room OBJ queries in the full data set was significant, Tukey's Least Significant Difference (LSD) for $p < .05$ was 9.88°. For the between-room data, shown on the right side of Figure 39, the near-facing to far-facing increase of 11.9° (77.1° to 89.0°) for between-room OBJ queries was also significant, Tukey's LSD for $p < .05$ was 10.42°. For the matched angle data, the near-facing to far-facing increase of 8.1° (41.0° to 49.1°) for within-room OBJ queries in the full data set was not statistically significant, Tukey's LSD for p < .05 was 14.95°. The critical difference of 14.95° is larger than the 8.1° increase described above. For the between-room data, however, the near-facing to far-facing increase of 25.0° (73.0° to 98.0°) for between-room OBJ queries was significant, Tukey's LSD for p < .05 was 13.70°.

It is possible that the accuracy of OBJ judgments was affected as a consequence of the yoked design and the facing object (*f*) manipulation. Although OBJ and JRD were matched (yoked) on standing at (*s*) and target (*t*) locations, different (*s*) and (*t*) object sets were used for near- versus far-facing locations for both OBJ and JRD queries. Even within a specific *f* location level (e.g., within-near *f* location, within-far *f* location), JRD and OBJ query object sets were never duplicated. Table 2 illustrates this point. The examples in Table 2 are all within-room queries. Remember, the near/far distinction (JRD near or OBJ far in Table 2) is not a room effect manipulation (whether the objects are in the same room or not), but a manipulation of the facing object (*f*) location. The

Table 2

Object Sets Are Not Identical for Near- and Far-facing Queries

	Level of Facing Object *(f)*			
Query Components	JRD near	JRD far	OBJ near	OBJ far
Standing at Object *(s)*	Chair	TV	***Chair***	***TV***
Facing Object *(f)*	Nightstand	Stove		
Target Object *(t)*	Couch	Stereo	***Couch***	***Stereo***

Note. Within-room query example. JRD standing at *(s)* and target *(t)* objects match the OBJ query. However, object sets differed from one query to another.

near-facing JRD query example contains three objects: chair, nightstand, and couch. This JRD query reads "You are standing at the chair, facing the nightstand. Point to the couch." The yoked OBJ query (same *s* and *t*) reads "You are standing in front of and directly facing the chair, point to the couch." For far-facing JRD queries, different standing at (*s*) and facing locations (*f*) were used. The far-facing JRD query example in Table 2 reads "You are standing at the TV, facing the stove, point to the stereo. The yoked (same *s* and *t)* OBJ query reads "You are standing in front of and directly facing the TV, point to the stereo." Again, the (*s*) and (*t*) object locations are the same for each matched JRD and OBJ query. However, the (*s*) and (*t*) object sets for specific query types were not identical. In the example shown in Table 2, the near-facing query used the chair and couch as the (*s*) and (*t*) objects but the far-facing query used TV and stereo as the (*s*) and (*t*) objects. Therefore, it is possible that differences in objects or object locations could have produced the effect of *f*-location for OBJ judgments. However, this would not explain the absence of an effect in the sketch map measure of OBJ judgments.

Experimental Design Alternatives

The matching procedure illustrated in Table 2 was used to avoid a potential problem that could have been created by manipulating the location of the facing object (*f*) as a repeated-measures factor. Table 3 illustrates an alternative or hypothetical design in which the location of the facing object (*f*) is the only object free to vary. Here we see that a far-facing JRD query could read "You are standing at the <u>chair</u>, facing the *<u>stove</u>*. Point to the <u>couch</u>", and a yoked far-facing OBJ query could read "You are standing directly in front of the <u>chair</u>, point to the <u>couch</u>." If this matching procedure had been used in the 2 x 2 x 2 design in this experiment with *f*-location as a repeated-measure, it would have created a situation in which participants in the OBJ judgment group would have received the same query twice. This problem would occur in both within-room and between-room queries as well as within levels of the facing object (*f*) location. With this alternative matching procedure OBJ participants could recognize repetition and, potentially, process the duplicate queries differently. For example, participants could remember how they

Table 3

Manipulating Only the Facing Object (f) Location

	Level of Facing Object *(f)*			
Query Components	JRD near	JRD far	OBJ near	OBJ far
Standing at Object	Chair	Chair	*Chair*	*Chair*
Facing Object	**<u>Nightstand</u>**	**<u>Stove</u>**		
Target Object	Couch	Couch	*Couch*	*Couch*

Note. Within-room query example. If only the facing object *(f)* is free to vary (**Nightstand** to **Stove**), participants in the JRD group would receive two distinct queries, even thought *s* and *t* remain the same. But the result of this design is that OBJ participants would receive the same query twice (*ital*).

responded previously. Furthermore, in this design, the duplicated OBJ queries would have to be directly compared to the JRD participants who would see 32 unique queries.

Another alternative would be to change the experimental design treating both the location of the facing object (*f*) and the room effect as between-subjects variables. This would eliminate the problem of repeated queries while at the same time allowing more control over the manipulation of objects sets, repeated objects, and the location of the facing object (*f*).

Generalizations

Because this is the first time the JRD and OBJ judgments have been directly compared, it is unknown how the comparisons of the two judgments would generalize to other experimental scenarios. However, Colle and Reid (1998, 2000, 2003) conducted a series of studies examining the performance of OBJ judgments when structural environmental configuration was manipulated. Their studies found a consistent performance, and a robust room effect, for OBJ judgments for many different environmental layouts. Colle & Reid (2000) attributed the rapid acquisition of within-room configural spatial knowledge to the structural aspects of rooms, a theory they called *characteristic enclosure frameworks*. Within-room performance was considered to depend on environmental structure. In the early studies, all rooms were connected by hallways that had to be traversed to get from room to room. However, Colle and Reid (2003) showed that the room effect was reduced when all rooms were directly connected and could be traversed directly from room to room. These results supported their structural explanation. Nevertheless, the variables underlying the learning of between-room configural spatial knowledge acquisition are less clear. Given that the major advantage of OBJ judgments over JRD judgments was found to occur for within-room queries, the object reference model may be appropriate for this structurally-related learning. It is not clear whether the advantages will generalize to between-room queries, which may entail different spatial learning principles.

ICJ judgments. This study compared JRD and OBJ judgments, but as described in the Introduction, there is a third proposed pointing judgment that was not investigated. Waller et al. (2004) argued for the use of immersively-cued judgments (ICJs). They found that pointing accuracy was better for ICJ than for JRD judgments. As was pointed out in the introduction, ICJ judgments do not discriminate between the quasi-Euclidean and object reference spatial memory models. JRD and OB J judgments are directional estimates made from recall, whereas ICJ judgments have the benefit of salient visual cues by placing participants in the actual environment during testing.

The differences that Waller et al. found between the ICJ and JRD judgments could be related to the results of the current study. Their results were obtained for queries that referred to a familiar outdoor environment, which could be considered to be similar to the between-room conditions in the present study. The distances were larger and out of sight and there was no obvious structure to the environment. Given that ICJ judgments were better than JRD judgments under these conditions and there were no consistent differences between OBJ and JRD in the between-room queries in the present study, it is conceivable that ICJ judgments would be better than OBJ judgments for these unstructured queries. On the other hand, participants were very familiar with the campus environment that was used for testing, differing from the current study's between-room conditions in which participants had minimal experience with the environment.

Therefore, OBJ judgments might perform better than JRD judgments with well learned unstructured outdoor environments. Answers to these questions await further testing of all three judgment types.

Practical Ramifications. I have emphasized the theoretical ramifications of judgment type, but the results of this thesis also have practical ramifications. First, if OBJ judgments are more accurate than JRD judgments, then using JRD judgments in spatial experiments may not result in an accurate representation of what people actually know about their environment. For example, as Colle and Reid (2000) pointed out, orientation and mobility instructors teach blind individuals to navigate in rooms by using a room's spatial structure. Blind individuals who use these strategies point more accurately when asked to face an object in a room (Hill, Rieser, Hill, Hill, Halpin, & Halpin, 1993). Valid measures of spatial memory representations would help to generalize results such as these. For example, to determine how to teach fire fighters to navigate in buildings from memory under conditions of low visibility. How should they be trained to navigate both within rooms and between rooms?

Second, understanding how spatial information is stored and used retrieved, and how the surrounding structures influence spatial knowledge, could have an important impact on how 3D images are created and presented to a user. Large scale design graphics, 3D medical visualizations, and graphic user interfaces for large data sets may be designed more effectively if we understand how people represent space. For example, large data sets commonly require operators to find and return to previously located items (e.g., Cockburn & McKenzie, 2004; Robertson, Czerwinski, Larson, Robins, Thiel, & vanDantzich, 1998; Robertson, vanDantzich, Czerwinski, Hinckley, Thiel, Robins, Risden, & Gorokhovsky, 2000). The design of these 3D displays, such as Data Mountain or Task Gallery, could benefit from understanding how people mentally represent space and the structural nuances (within-room/between-room) seen in this study.

APPENDIX A
SCENARIO

Practice

In this study you will be asked to navigate in a virtual environment representing a local shopping center. A virtual environment is a computer generated environment that you can simulate moving around in. You will use the arrow keys on the keyboard to move around in the environment. The up arrow will move you one step forward, the down arrow will move you one step back, the left arrow will turn, or pivot you, to the left and the right arrow will turn, or pivot you, to the right. You can move as fast or slow as you want to, this is not a timed experiment. I will assign you tasks as you go through the environment. If you are moving when you hear me ask you to stop, you should stop moving and wait until I tell you to continue. If you have any questions at this point, please let me know. If not, we will begin the training portion of the experiment.

You are standing at the end of a hallway. Your first task is to move straight down the hall and stand in front of the red block. You will not actually be interacting with the block, you will simply say "I'm there," once you get to the block. The reason I ask you to say “I’m there” is so that I know you’re exactly where you want to be in relation to that object and that you don’t intend to make anymore movements or adjustments. I will then give you your next set of instructions.

Now that you have reached the red block, you continue down the hall to your right to find the blue block.

You see a room to your right and go inside and find the green block. When you have located the green block, stand directly in front of it. You should be able to read the writing on the top of the green block just like you have a piece of paper directly in front of you.

You have completed the training portion of this study. Now that you have had some experience moving around in a virtual environment, we will begin the experiment. When you have a full understanding of your task, I will transport you into the experimental environment where you will receive instructions about your task. Do you have any questions?

Task

In this study, you have been hired to do inventory for a small shopping center currently under renovation, so not all the rooms are occupied. Right now only 5 rooms are being use for stores or other purposes: an employee office, an appliance store, a vending machine area, an electronics store, and a furniture store. Your task will be to collect detailed information about the items in each area, including make, model, condition and location. Your job will be to inventory everything in the room. Before taking inventory, you will need to go to the employee office to sign in and take care of paperwork.

I will give you tasks that you need to complete, including objects to interact with. When you are asked to interact with one of the objects, just walk up to the front of an object's location and stand about an arm's length away from it, just like you did in the training session. When you get there, tell me by saying, "I'm there." I need to hear you say this so I know that you are in the position you want to be and do not intend to make any more moves with the arrow keys. I will then tell you what to do next as if you have already performed the task. I will provide you with all other necessary information you need to complete the study. As you perform your tasks, think about the environment as if you are actually in the building walking around. Pay attention to the details about the building so that if you are given instructions to perform a task in a certain location you could "virtually walk" to the location without getting confused or lost. Are you ready?

You have arrived at the employee office and you have met your new boss. You participate in a two-hour orientation session that includes an overview of your duties, filling out paperwork and planning your day. After the orientation, your boss tells you to put your things away and she tells you a safe storage area for employee belongings is in the lockers.

“Walk over to the lockers.”
[Command given to move to next task object]

Once your belongings are locked away, your boss gives you copies of the tax withholding paperwork you filled out earlier. You will need to file this paperwork for the payroll clerks.

“Go over to the file cabinet.”

You file your paperwork and you’re ready to start. You glance at your watch and see that it’s almost lunchtime. You hope that your inventory duties leave you enough time to pick up some lunch, but you don’t have any cash. You notice that there is an ATM in the office so you go over to get some cash.

“Walk over to the ATM.”

You have your cash and you’re ready for work. But before you go, you need to call you roommate. He/she dropped you off at work today because you’re car is in the shop. Your boss told you that you would be finished around 3pm and you want to make sure your roommate picks you up on time. Since you locked your cell phone in the lockers, you need to use the office phone.

“Walk over to the phone.”

Your roommate isn't home, so you leave a message. Your boss hands you the inventory sheets and you see that you'll be starting in the appliance store. Go out the door and down the hall to the appliance store. You have arrived at the appliance store. You see a stove off to your left.

"Walk over to the stove."

You record all the information about the stove on the inventory sheet, including the fact that it is gas stove. You glance around and see an air conditioner.

"Go over to the air conditioner."

The air conditioner is an older model but looks to be in good condition and you take down the make, model and dimensions for your inventory sheet. You look around for another item and see a refrigerator.

"Walk over to the refrigerator."

The refrigerator is a side-by-side and looks to be in good condition. You record all the information and look to see if you have missed anything in the room. You see a washing machine.

"Go over to the washing machine."

The washing machine is a top-loader and you note this fact on your inventory sheet. You have trouble finding a make and model, so you write down as much information as you can, including color and dimensions. It looks like you are done in this room so you head out into the hallway to find the next store on your list, an electronics store. Go out the door and down the hall to the electronics store.

While you are on your way, you see a vending machine area. You look at your watch and see that it is noon so you decide to grab something to eat before you get to the electronics store.
As you enter the vending machine area, you see a snack machine.

"Walk over to the snack machine."

You find some chips in slot B6 and make your purchase. Looking for something to drink, you see a Pepsi machine.

"Walk over to the Pepsi machine."

You buy a Pepsi and then take a minute to finish eating your chips and drinking. You look around and see an ice cream machine and decide to have dessert.

“Go over to the ice cream machine.”

You want to get a chocolate covered Dove bar but see that they are out of those so you get a Fudgcicle instead. Finishing your lunch, you notice a juice machine. You think it might be nice to have something to drink while you are finishing up your inventory.

“Walk over to the juice machine.”

You choose a orange-pineapple juice and take it with you when head out to continue your work. Go out the door and down the hall to the electronics store. As you enter the electronics store, you see a copier.

“**Walk over to the copier.”**

This is a large, industrial copier with an attached feeder and sorter. You make note of the make, model, and extra features on your inventory sheet. You look around and see a TV.

“**Go over to the TV.”**

This is a 25”, color TV. You see that it is made by RCA, but some of the serial number is unreadable. You write down as much as you can on your sheet. Since the TV is on the stand and you were told to inventory everything, you make note of its dimensions, the color and the material it’s made of. You look around for another item and you see a stereo.

“**Walk over to the stereo.”**

This stereo is a premium quality system, with digital bass boost and satellite speakers. You note, however, that the speakers are made by a different company so you record this information separately. Here again, the stereo is on a separate stand. Since you made an inventory of the TV stand, you do the same for this one. You don’t see any other items in the room, but you notice a fire extinguisher. Since your boss told you to inventory everything in the room, you think you should include the fire extinguisher, too.

“**Go over to the fire extinguisher.”**

You take detailed notes of the fire extinguisher, including capacity and condition of the container. You see that a furniture store is the last store on your list, so you head out the door and down the hall to the furniture store. When you enter the furniture store, you see a chair on your left and decide to start there.

“**Walk over to the chair.”**

You record the dimensions, style and material, but can’t find the manufacturer information. You turn the chair over to see if there is a label. While doing this, the manufacturer brochure falls out

from under the cushion. You record this information on your inventory sheet. You look around for another item. You see an end table.

“**Go over to the end table.”**

The end table looks to be in damaged condition; there is a big knick out of the front left leg. You note this, along with the fact that the top drawer does not work. You record all the pertinent dimensions, make and model information, and look around for another item. You see a couch.

“**Go over to the couch.”**

Just like the chair you don’t see a manufacturer label. But this time you look under the cushion first and find the information you need. You record all the necessary information on your inventory sheet. You look around and see one more item in the room – a fish tank.

“**Walk over to the fish tank.”**

You notice that there are several fish in the tank and make note of this on your inventory sheet. Like the TV and stereo, this tank has a stand, so you record the dimensions, materials and color.

You look around the room and realize that you have finished your inventory duties. It’s time to head back to the office, pick up your things and leave for the day.

APPENDIX B
JRD POINTING TASK AND TOUCH SCREEN INSTRUCTIONS

Now that you have had some experience with the virtual environment in the shopping center, we would like to ask you some questions about the locations of objects in this environment.

Here is how the questions will be phrased. You are to imagine that you are standing at one object in the environment, facing another object. Then you'll be asked to point to a third object. Let's try it now.

Come out here in the hallway and I will show you what to do. On the door you'll see a pizza sign. Walk up to the pizza sign. Now, behind you, you'll see a chair again the other wall. Stand at the pizza sign and face the chair. Now, you'll notice a box fan sitting on a chair to your left. From where you're standing, point to the location of the fan. Now come back in here with me and let me show you what I'd like you to do.

While you are standing here, imagine you are standing at the pizza sign, facing the chair. Now, from your location at the pizza sign, imagine the location of the fan. Point to where the fan would be.

Okay come over here. Instead of pointing, I want you to use this touch screen monitor to show me the same information. This display is a pointing device. The black, center circle represents the top of your head and the line at the top of the black circle represents your nose. This line lets you know in which direction you are standing and facing. The message on the screen says to "Touch the black center circle to begin practice". When you touch the black center circle, a question will appear at the top of the screen. Once your question appears, please concentrate on answering the question and nothing else.

Tell me the direction of the object you are asked to point to by touching either a light or dark blue segment on the outer circle. When you touch the outer circle, that particular spot, or segment, will turn red. If you want to change your answer, pick up your finger and touch a new space on the circle. When you have the red space where you want it, you'll touch the *submit answer* button to record your response. Once you touch submit answer, you may not change your mind.

You need to know that this touch screen does not respond to dragging your finger. Do not drag your finger across the touch screen; it will not record your response or it will record your response incorrectly. If you need to change your answer, simply pick up your finger and touch a new space.

So when you have the red segment where you want it, you'll touch Submit Answer. Now, after each question, and before you touch the black circle for a new question, I will ask you how confident you are of your response. On the clipboard to your left, you'll see a scale with 7 possible responses. 7 is completely confident of your response, 6 is very confident, 5 is somewhat confident, 4 is neither confident nor unconfident, 3 is somewhat unconfident, 2 is very unconfident, and 1 is completely unconfident of your response. Please answer my question by choosing one of the numbers in the scale.

These next few comments are very important. After you have submitted your answer, the top message box will go blank. When you are ready for a new question, touch the black center circle again. Do not touch this circle until you are ready to concentrate on and respond to the question. While the question is visible in the message box, please do not do anything but concentrate on answering the question. If you have any questions for me, please ask them only before you touch the black center circle or after you have touched the *submit answer* button.

When there are no more questions, you will see a dialogue box that says, "the experiment is done! Please notify your experimenter". Do not touch the "ok" button … I will do that for you.

Okay, for practice, you'll get two questions. While you're practicing, do not ask me any questions until after you have touched *submit answer*. Go ahead and answer the first practice question.

Great, go ahead and touch the black center circle to get the second practice question.

Okay, great. Now let's start the questions from the shopping center. The touch screen will ask you questions similar to the practice ones. While you are answering questions, remember it is very important that you imagine you are standing at an object in the environment, facing another object. Try to answer each one. Take your time and try to imagine the virtual environment before answering each question. It is not important how fast you respond. We would like you to be as accurate as possible. Do you have any questions before you get started?

APPENDIX C

OBJ POINTING TASK AND TOUCH SCREEN INSTRUCTIONS

Now that you have had some experience with the virtual environment in the shopping center, we would like to ask you some questions about the locations of objects in this environment.

Here is how the questions will be phrased. You will be asked to imagine that you are in front of and squarely facing and object in the environment. Then you'll be asked to point to another object. While you are answering questions, it is very important that you imagine yourself in front of and squarely facing each indicated object from an arm's length away. Let's try it now.

Come out here in the hallway and I'll show you what to do. On the door you'll see a pizza sign. Walk up to the pizza sign, stand squarely in front of it and an arm's length away. Now, you'll notice a box fan to your right. While you are facing the pizza sign, point to the fan. Now let's go back in the room I'll show you what I'd like you to do.

While you are standing here, imagine you are directly in front of and squarely facing the pizza sign. Now, imagine the location of the fan. Point to where the fan would be.

Okay come over here. Instead of pointing, I want you to use this touch screen monitor to show me the same information. This display is a pointing device. The black, center circle represents the top of your head and the line at the top of the black circle represents your nose. This line lets you know in which direction you are standing and facing. The message on the screen says to "Touch the black center circle to begin practice". When you touch the black center circle, a question will appear at the top of the screen. Once your question appears, please concentrate on answering the question and nothing else.

Tell me the direction of the object you are asked to point to by touching either a light or dark blue segment on the outer circle. When you touch the outer circle, that particular spot, or segment, will turn red. If you want to change your answer, pick up your finger and touch a new space on the circle. When you have the red space where you want it, you'll touch the *submit answer* button to record your response. Once you touch submit answer, you may not change your mind.

You need to know that this touch screen does not respond to dragging your finger. Do not drag your finger across the touch screen; it will not record your response or it will record your response incorrectly. If you need to change your answer, simply pick up your finger and touch a new space.

So when you have the red segment where you want it, you'll touch *Submit Answer*. Now, after each question, and before you touch the black circle for a new question, I will ask you how confident you are of your response. On the clipboard to your left, you'll see a scale with 7 possible responses. 7 is completely confident of your response, 6 is very confident, 5 is somewhat confident, 4 is neither confident nor unconfident, 3 is somewhat unconfident, 2 is very unconfident, and 1 is completely unconfident of your response. Please answer my question by choosing one of the numbers in the scale.

These next few comments are very important. After you have submitted your answer, the top message box will go blank. When you are ready for a new question, touch the black center circle again. Do not touch this circle until you are ready to concentrate on and respond to the question. While the question is visible in the message box, please do not do anything but concentrate on answering the question. If you have any questions for me, please ask them only before you touch the black center circle or after you have touched the *submit answer* button.

When there are no more questions, you will see a dialogue box that says, "the experiment is done! Please notify your experimenter". Do not touch the "ok" button … I will do that for you.

Okay, for practice, you'll get two questions. While you're practicing, do not ask me any questions until after you have touched *submit answer*. Go ahead and answer the first practice question.

Great, go ahead and touch the black center circle to get the second practice question.

Okay, good. Now let's start the questions from the shopping center. The touch screen will ask you questions similar to the practice ones. While you are answering questions, remember it is very important that you imagine yourself in front of and squarely facing each indicated object from an arm's length away, even if this was not your exact location within the virtual environment. Try to answer each one. Take your time and try to imagine the virtual environment before answering each question. It is not important how fast you respond. We would like you to be as accurate as possible. Do you have any questions before you get started?

APPENDIX D
QUERIES AND CORRESPONDING ANGLES

Within-room Queries

s standing at	**f** facing	**t** target	*JRD angle*	*OBJ angle*	*Quadrant JRD/OBJ*
Chair	Nightstand	**Couch**	98	98*	Right/Right
TV	Fire extinguisher	**Stereo**	202	202*	Back/Back
ATM	Phone	**File cabinet**	30	30*	Front/Front
Fish tank	Nightstand	**Couch**	243	243*	Left/Left
Snack machine	Ice cream	**Pepsi machine**	335	299	Front/Left
Phone	File cabinet	**ATM**	117	180	Right/Back
File cabinet	ATM	**Lockers**	332	278	Front/Left
TV	Copier	**Fire extinguisher**	228	0	Left/Front
Stove	Copier	**Washer**	296	296*	Left/Left
Fish tank	TV	**Chair**	323	323*	Front/Front
ATM	Nightstand	**Lockers**	69	69*	Right/Right
Copier	Couch	**Stereo**	171	171*	Back/Back
Pepsi machine	ATM	**Ice cream machine**	166	110	Back/Right
Fire extinguisher	Fish tank	**Copier**	48	155	Right/Back
Lockers	Stereo	**ATM**	287	342	Left/Front
Washer	Ice Cream	**Stove**	155	111	Back/Right

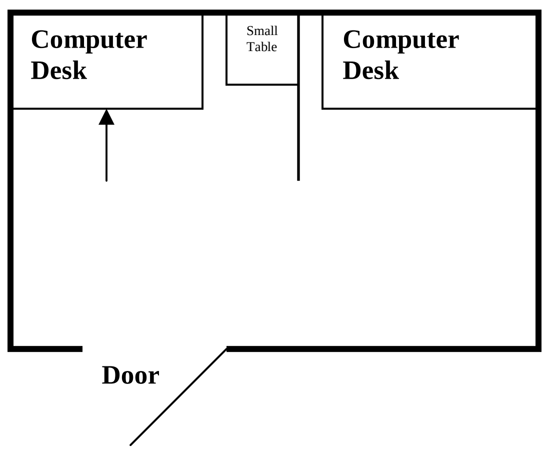
Between-room Queries

s standing at	**f** facing	**t** target	*JRD angle*	*OBJ angle*	*Quadrant JRD/OBJ*
Snack	Juice	**Chair**	143	143*	Back/Back
Stove	Air conditioner	**Fire extinguisher**	355	355*	Front/Front
TV	Fire extinguisher	**Couch**	100	100*	Right/Right
Fish tank	Nightstand	**Refrigerator**	294	294*	Left/Left
Air conditioner	Washer	**Lockers**	219	24	Back/Front
Copier	TV	**Ice cream machine**	266	133	Left/Right
Lockers	ATM	**Stove**	20	5	Front/Front
Pepsi machine	Juice machine	**Nightstand**	72	223	Right/Back
Stereo	Washer	**Phone**	332	332*	Front/Front
Phone	Chair	**Pepsi machine**	295	295*	Left/Left
Nightstand	ATM	**TV**	87	87*	Right/Right
Copier	Couch	**Juice machine**	142	142*	Back/Back
Fire extinguisher	File cabinet	**Air conditioner**	19	173	Front/Back
Chair	Lockers	**Snack machine**	63	234	Right/Left
Snack machine	Refrigerator	**Fire extinguisher**	210	102	Back/Right
Refrigerator	Fish tank	**Juice machine**	306	241	Left/Left

s-f-t indicates JRD task objects.
Bold objects indicate task objects for the corresponding OBJ query.
* indicates matched angles.
Highlighted = near-facing *f*-location (*s* and *f* in the same room).

APPENDIX E
SKETCH MAP DRAWING INSTRUCTIONS

On the next page, which is blank, we would like you to draw a map of the virtual environment you just explored. Please include all **rooms** and **walkways** and include all **objects** you interacted with in the environment (a list of objects is given below). Simply draw a square or rectangle to represent an object and place the objects as accurately as you can within the map boundaries. You will need to label the rooms and objects, and we would like you to draw an arrow pointing in the same direction you would be if you were <u>squarely</u> facing the front of the object. For example, if you were to draw a map of this experimental booth, including the object you interacted with, it may look like this:



The arrows represent you sitting and facing the desk. Be sure that the arrows you draw represent you <u>squarely facing</u> each object. Be sure to label the objects, rooms, and entrances to the rooms. We do not expect perfectly straight lines, but please try to draw as carefully and precisely as possible. Be sure to include all walls of each room, as well as both sides of each walkway. Do not include the environment you explored during training. It is not a part of the experimental environment. If you have any questions, please ask the experimenter now.

The following is a list of the objects in the environment. They are listed in random order. Please <u>include them all</u> in your environment. If you can't remember an object at all, tell the experimenter.

Washing machine	Couch	Juice machine
Stove	T V	Nightstand
Copy machine	Snack machine	Refrigerator
Ice cream machine	Chair	Stereo
Fish Tank	Fire extinguisher	Air conditioner
Phone	ATM	Pepsi machine
Filing cabinet	Lockers	

APPENDIX F
POINTING DATA – ANOVA RESULTS

ANGULAR ERROR

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	4473.25814	1	4473.25814	5.495586619	0.023
S(J)	37442.74967	46	813.97282		
Room	38540.41699	1	38540.41699	102.1720808	< .0001
Judgment x Room	8196.72005	1	8196.72005	21.72981013	< .0001
S(J) x Room	17351.69889	46	377.2108455		
Within	8694.902507	1	8694.902507	30.13473046	< .0001
Judgment x Within	1527.013184	1	1527.013184	5.29231129	0.026
S(J) x Within	13272.5765	46	288.5342717		
Between	425.5678711	1	425.5678711	1.326131546	0.2554
Judgment x Between	1409.708496	1	1409.708496	4.392857249	0.0416
S(J) x Between	14761.8252	46	320.9092434		
Total	146096.4375	191			

***MATCHED* ANGULAR ERROR**

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	454.79297	1	454.79297	**0.545962118**	0.464
S(J)	38318.54948	46	833.011195		
Room	37576.02083	1	37576.02083	**46.4055941**	< .0001
Judgment x Room	7487.505208	1	7487.505208	**9.246911119**	0.0039
S(J) x Room	37247.59896	46	809.7304121		
Within	10453.1569	1	10453.1569	**15.82104255**	0.0002
Judgment x Within	3962.297526	1	3962.297526	**5.997009165**	0.0182
S(J) x Within	30392.76432	46	660.7122679		
Between	3622.969401	1	3622.969401	**6.530127211**	0.014
Judgment x Between	3904.688151	1	3904.688151	**7.037903864**	0.0109
S(J) x Between	25521.1862	46	554.8083956		
Total	198941.5299	191			

CONFIDENCE

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	3.69214	1	3.69214	**1.32048378**	0.2564
S(J)	128.61833	46	2.79605		
Room	35.98836	1	35.98836	**91.1403776**	< .0001
Judgment x Room	5.37508138	1	5.37508138	**13.61237108**	0.0006
S(J) x Room	18.16389974	46	0.394867386		
within	10.75016276	1	10.75016276	**52.42165016**	< .0001
Judgment x Within	2.1520651	1	2.1520651	**10.49639394**	0.0022
S(J) x Within	9.433268229	46	0.205071048		
Between	0.041666667	1	0.041666667	**0.291831879**	0.5917
Judgment x Between	0.375	1	0.375	**2.626486915**	0.1119
S(J) x Between	6.567708333	46	0.142776268		
Total	221.1576822	191			

***MATCHED* CONFIDENCE**

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	2.46387	1	2.46387	**0.788197888**	0.2564
S(J)	143.79362	46	3.12595		
Room	**29.39251**	1	29.39251	**61.31957155**	< .0001
Judgment x Room	4.30501	1	4.30501	**8.950798929**	0.0044
S(J) x Room	22.12434896	46	0.480964108		
Within	11.51627604	1	11.51627604	**35.24620982**	< .0001
Judgment x Within	2.922526042	1	2.922526042	**8.944555142**	0.0045
S(J) x Within	15.02994792	46	0.326737998		
Between	2.190104167	1	2.190104167	**.2918318**	0.5917
Judgment x Between	0.010416667	1	0.010416667	**0.025831812**	0.873
S(J) x Between	18.54947917	46	0.403249547		
Total	252.298109	191			

LATENCY

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	25.60708	1	26.248	**0.245834877**	0.6224
S(J)	4911.48	46	106.771		
Room	212.486907	1	212.486907	**12.37857159**	0.001
Judgment x Room	138.2399	1	138.2399	**8.053301296**	0.001
S(J) x Room	789.6187117	46	17.16562417		
Within	91.210525	1	91.210525	**6.334629378**	0.0154
Judgment x Within	0.433104	1	0.433104	**0.030079404**	0.8631
S(J) x Within	662.3409075	46	14.39871538		
Between	37.918958	1	37.918958	**4.820168463**	0.0332
Judgment x Between	17.622479	1	17.622479	**2.24012794**	0.1413
S(J) x Between	361.8695307	46	7.866728927		
Total	7248.828103	191			

***MATCHED* LATENCY**

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	0.099724	1	0.099724	**0.000936371**	0.97572
S(J)	4899.07	46	106.5015217		
Room	212.695	1	212.695	**12.04601122**	0.0011
Judgment x Room	137.4711983	1	137.4711983	**7.785701046**	0.00764
S(J) x Room	812.2165341	46	17.65688118		
Within	241.9405563	1	241.9405563	**16.32773031**	0.0002
Judgment x Within	29.2987994	1	29.2987994	**1.977274486**	0.1664
S(J) x Within	681.617431	46	14.81777024		
Between	47.07220551	1	47.07220551	**3.399831167**	0.0717
Judgment x Between	6.216162628	1	6.216162628	**0.448967776**	0.5062
S(J) x Between	636.890877	46	13.84545385		
Total	7704.588488	191			

APPENDIX G
MAP DATA – ANOVA RESULTS

PARALLEL ANALYSIS

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	4310.651	1	4310.651	4.775041	0.034
S(J)	41526.34049	46	902.74653		
Room	16823.48	1	16823.48	63.25868	<.0001
Judgment x Room	2075.399	1	2075.399	7.803796	0.00757
S(J) x Room	12233.59	46	265.9473		
Within	3337.042	1	3337.042	12.39513	0.001
Judgment x Within	1053.375	1	1053.375	3.912664	0.0539
S(J) x Within	12384.21	46	269.2219		
Between	1017.253	1	1017.253	3.639729	0.0627
Judgment x Between	32.08594	1	32.08594	0.114803	0.7363
S(J) x Between	12856.35	46	279.4858		
Total	107649.7764	191			

***MATCHED* PARALLEL**

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	6518.75814	1	6518.75814	6.36977	0.01512
S(J)	47075.94466	46	1023.3901		
Room	14555.97949	1	14555.97949	29.55444	<.0001
Judgment x Room	3062.00814	1	3062.00814	6.217094	0.0163
S(J) x Room	22655.65299	46	492.5142		
Within	4390.893	1	4390.893	7.531297	0.0086
Judgment x Within	1518.053	1	1518.053	2.603777	0.1134
S(J) x Within	26818.9	46	583.0196		
Between	1134.375	1	1134.375	1.431814	0.2376
Judgment x Between	68.34375	1	68.34375	0.086264	0.7703
S(J) x Between	36444.16	46	792.2643		
Total	164243.0682	191			

JRD SCORING

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	959.6644	1	959.6644	0.869859	0.3559
S(J)	50749.07747	46	1103.24081		
Room	6440.333	1	6440.333	26.50276	<.0001
Judgment x Room	15.18575	1	15.18575	0.0625	0.8037
S(J) x Room	11178.28	46	243.0062		
Within	9167.485	1	9167.485	23.82616	<.0001
Judgment x Within	30.51579	1	30.51579	0.07931	0.7795
S(J) x Within	17699.21	46	384.7654		
Between	171.6681	1	171.6681	0.533038	0.469
Judgment x Between	598.1265	1	598.1265	1.857213	0.1796
S(J) x Between	14814.57	46	322.0559		
Total	111824.116	191			

***MATCHED* JRD SCORING**

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	1579.82064	1	1579.82064	1.07239	0.30582
S(J)	67766.43424	46	1473.18335		
Room	6449.02376	1	6449.02376	20.66314	<.0001
Judgment x Room	224.79199	1	224.79199	0.72025	0.4005
S(J) x Room	14356.73112	46	312.10285		
Within	9150.39	1	9150.39	15.23725	0.0003
Judgment x Within	91.5532	1	91.5532	0.152455	0.698
S(J) x Within	27624.27	46	600.5277		
Between	3.760448	1	3.760448	0.004251	0.948
Judgment x Between	1926.042	1	1926.042	2.177248	0.1469
S(J) x Between	40692.64	46	884.6225		
Total	169865.4574	191			

OBJ SCORING

Source	SSQ	Df	*MS*	***F***	*p*
Judgment	531.252	1	531.252	0.612365	0.43791
S(J)	39906.93278	46	867.54202		
Room	22840.41	1	22840.41	57.12338	<.0001
Judgment x Room	582.3263	1	582.3263	1.456385	0.23368
S(J) x Room	18392.8	46	399.8435		
Within	1240.742	1	1240.742	5.615348	0.0221
Judgment x Within	98.26318	1	98.26318	0.444719	0.5082
S(J) x Within	10163.96	46	220.9556		
Between	877.5527	1	877.5527	5.149208	0.028
Judgment x Between	11.51628	1	11.51628	0.067574	0.7961
S(J) x Between	7839.54	46	170.4248		
Total	102485.2952	191			

***MATCHED* OBJ SCORING**

Source	SSQ	Df	MS	F	p
Judgment	862.75521	1	862.75521	0.76227	0.38716
S(J)	52064.18099	46	1131.83002		
Room	23507.81308	1	23507.81308	35.07401	<.0001
Judgment x Room	513.5198	1	513.5198	0.766179	0.3859
S(J) x Room	30830.79	46	670.2346		
Within	145.0419	1	145.0419	0.265171	0.609
Judgment x Within	232.8154	1	232.8154	0.425642	0.5174
S(J) x Within	25160.83	46	546.9746		
Between	195.5102	1	195.5102	0.411256	0.5245
Judgment x Between	130.6669	1	130.6669	0.274858	0.6026
S(J) x Between	21868.32	46	475.3983		
Total	155512.2435	191			

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